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John M. Wakeman  
*Louisiana Tech University*

Paul R. Ramsey  
*Louisiana Tech University*

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## A SURVEY OF POPULATION CHARACTERISTICS FOR RED DRUM AND SPOTTED SEATROUT IN LOUISIANA

JOHN M. WAKEMAN AND PAUL R. RAMSEY

Department of Zoology, Louisiana Tech University,  
Ruston, Louisiana 71272

**ABSTRACT** Red drum and spotted seatrout stocks were sampled from seven separate study areas along the Louisiana coast and from one estuarine area in Texas, with additional intensive temporal (monthly) and microgeographic (range of salinity regimes) samplings being carried out in one Louisiana study area. Condition coefficients, which did not appear to be affected by salinity regimes within the microgeographic sampling area, varied significantly according to study area, with Texas fish showing significantly lower condition coefficients than Louisiana fish. Von Bertalanffy growth equations were fitted and annual mortality rates were estimated to obtain preliminary estimates of yields, population numbers, and densities of these species in Louisiana.

### INTRODUCTION

The popularity of red drum, *Sciaenops ocellatus* (Linnaeus), and spotted seatrout, *Cynoscion nebulosus* (Cuvier), as game and commercial fish on the Louisiana coast has resulted in increasing tension between sports fishermen and commercial fishermen, and caused concern that populations of these species in Louisiana may be declining (Perrel et al. 1980). Other Gulf coast states, facing similar controversies, have recently enacted, or are considering enactment of laws restricting or banning commercial fishing for these species.

Assessment and effective management of such fish stocks generally requires reasonable estimates of population parameters such as natural mortality, fishing mortality, density, growth rates, and recruitment. Length-weight relationships and condition coefficients may also provide useful insights concerning the relative well-being of fish stocks in different areas (Bagenal and Tesch 1978).

The primary purpose of this study was to evaluate the status of red drum and spotted seatrout populations in Louisiana, to supplement the growing body of data on the biology of these species in the northern Gulf of Mexico (Overstreet 1983a and 1983b), and to provide estimates of the various population parameters needed for more effective management of these important species in Louisiana.

### MATERIALS AND METHODS

Red drum and spotted seatrout populations were sampled from seven study areas along the Louisiana coast, and from one estuarine area in Texas. Most samples contained more than 40 individuals of each species. The study areas and the seasons in which they were sampled are indicated in Figure 1.

Louisiana study area 4 (Terrebonne Parish) was selected for more intensive temporal and microgeographic sampling. For this purpose, four subareas within this study area were established and sampled at approximately monthly intervals

over the course of a year. The four subareas—Cocodrie, Moss Bay, Bay St. Elaine and Terrebonne Bay—are separated in a north-south direction by distances of 4, 9, and 7 km, respectively, and represent different salinity regimes ranging from relatively low at Cocodrie (<10 ppt) to relatively high at Terrebonne Bay (>25 ppt).

Fish were collected by both netting and angling. The majority of fish were taken in a 100-m variable mesh, monofilament gill net (stretched mesh size ranged from 2.5 to 13 cm), which was usually set in a semicircle from the shore, enclosing an area of approximately 0.1 hectares. The enclosed surface was then struck with oars to drive fish into the net. The effectiveness of such netting operations was evaluated on three occasions by blocking off the enclosed area after such "strikes" and using rotenone to ascertain the total numbers of unnetted red drum and spotted seatrout. These evaluations indicated that the netting procedures netted approximately 20% of the catchable red drum and spotted seatrout enclosed within the nets, and that the size distribution of catchable but unnetted fish was similar to that of fish taken in the variable mesh net. Although netting success varied widely during the course of the study, the average capture rate was close to two red drum and four spotted seatrout per set.

A total of 402 red drum and 614 spotted seatrout were obtained in the entire study. Fish were sexed, weighed to the nearest gram, and their standard lengths were measured to the nearest 0.1 cm. To linearize the relationship between weight (W) and standard length (SL), the regression model  $\log W = \log a + b(\log SL)$  was fitted to weight/length data by sex and by coastal area. Analysis of covariance was used to test for differences between regressions.

Condition factors ( $100 W/SL^3$ ) of whole fish were calculated for all fish collected, tested for normality and averaged according to sex, season, and coastal study area. Effects of these variables were evaluated by Duncan's comparison-of-means test. Similar comparisons were made among mean condition factors of fish from the four subareas in Terrebonne Parish to establish any temporal and/or

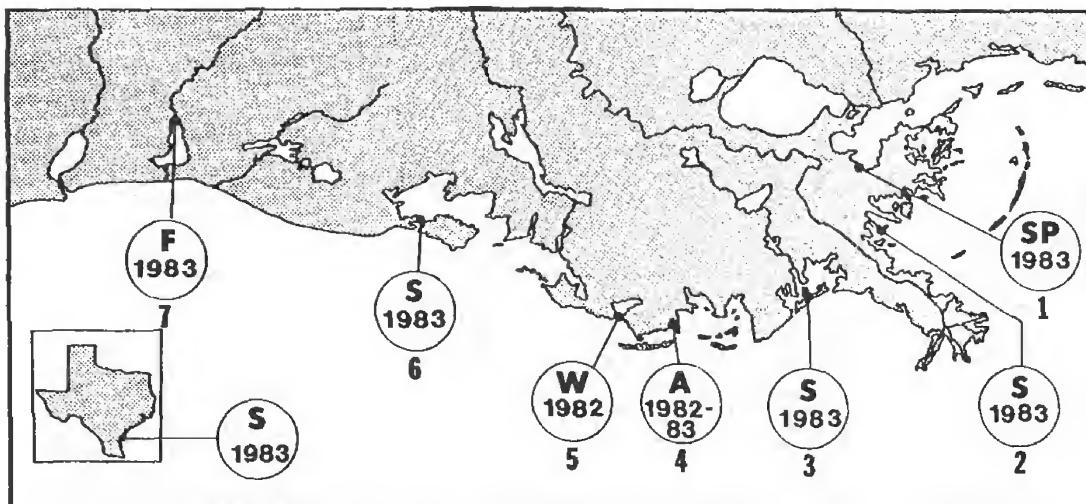


Figure 1. Sampling areas in Louisiana and in Texas (insert) with seasons when red drum and spotted seatrout were collected from each area (SP = spring, S = summer, F = fall, and A = all seasons).

microgeographic differences in condition factors for these species.

Age and growth were evaluated by two methods: (1) by seasonal and overall length-frequency analyses; and (2) by scale reading. For the latter, plastic scale impressions were prepared from scales taken from the shoulder region of each fish and examined with a microprojector. Standard scale-aging criteria (Lux 1971) and published criteria for the scale-aging of sciaenids (Schlossman and Chittenden 1981) were used to identify annuli.

Waldford plots (Waldford 1946) were fitted to obtain estimates of asymptotic standard length ( $L_{\infty}$ ) and growth coefficients (K) for red drum and spotted seatrout. These estimates were then used to fit von Bertalanffy growth equations for these species in Louisiana.

## RESULTS AND DISCUSSION

### *Weight-Length Relationships*

Analysis of covariance revealed no significant differences

( $P > 0.05$ ) between sexes for the slope or elevation of log weight regressed against log standard length for either species (red drum,  $F = 1.86$ ; spotted seatrout,  $F = 2.25$ ). For this reason, sexes were combined to obtain weight-length regression equations for Louisiana and Texas fish (Table 1). Predicted weights from the Louisiana equations for 30 cm (standard length) red drum and spotted seatrout were 509 g and 414 g, respectively, agreeing closely with Overstreet's (1983a, b) predictions of 511 g and 409 g for Mississippi red drum and spotted seatrout. However, because the majority of fish collected in this study were between 1 and 3 years of age, caution should be used in applying the equations to older or younger fish.

### *Condition Factors*

Because the condition factor of fish ( $K_c$ ) is often influenced by season, sex, maturity stage, and age, such parameters are important considerations when condition factors are compared (Everhart et al. 1975). In analyzing  $K_c$  values of fish collected in this study, the Kolmogorov-

TABLE I  
Regressions of weight (W) in g vs. standard length (SL) in cm for red drum (R) and spotted seatrout (S) collected from Louisiana and from Texas. The regression model is  $\log W = \log a + b(\log SL)$ . N = number of fish.

State	Species	N	Log a	b	r <sup>2</sup>	Predicted weight for 30 cm fish
LA	R	363	-1.4590	2.8203	.99	509 g
LA	S	561	-1.6664	2.8996	.98	414 g
TX	R	36	-1.6718	2.9516	.99	488 g
TX	S	54	-1.5719	2.8204	.97	393 g

TABLE 2

Seasonal condition factors  $\pm$  SE of red drum and spotted seatrout. R = red drum; S = spotted seatrout; N = number of fish.

Species	Spring N	Summer (N)	Fall (N)	Winter (N)
R	1.83 $\pm$ .02	(53)	1.99 $\pm$ .01	(217)
S	1.63 $\pm$ .02	(51)	1.58 $\pm$ .01	(269)

Smirnov test statistic (D) was found to be less than the critical value of D<sub>.05</sub> for all collections. Thus, there was no reason to reject the hypothesis that this characteristic was distributed normally (Sokal and Rohlf 1969).

Analysis of variance revealed that the K<sub>c</sub> values obtained in this study varied significantly with study area and with season, but not with sex. For this reason, sexes were combined to obtain average seasonal condition factors (Table 2) and mean condition factors for each estuarine study area (Table 3).

In both species, high condition factors appear to be associated with seasons immediately prior to spawning. Thus, red drum K<sub>c</sub> values were highest in summer prior to the fall spawning period, while those of spotted seatrout were highest in spring immediately preceding their spawning period, which begins in late spring and continues throughout the summer.

The low variability for K<sub>c</sub> values within each estuarine study area (Table 3) suggests that condition factors may be useful in comparing the relative well-being of subpopulations of these species, provided that the fish from each area are collected during the same season. Duncan's multiple range test indicated that red drum and spotted seatrout from the Port Aransas area of Texas (collected during summer 1983) were significantly ( $p < 0.05$ ) less robust than Louisiana fish collected during the same season (Table 3).

Analysis of condition factors of fish from coastal study area 4 revealed no significant differences between the four subareas sampled, indicating that the salinity regimes (low,  $< 10$  ppt; intermediate, 10–25 ppt; and high,  $> 25$  ppt) represented within this microgeographic range have little effect on the robustness of these euryhaline species. Condition factors for both species from study area 4 did,

however, vary significantly with season, following the same seasonal trends shown in Table 2.

#### Length Frequencies, Age and Growth

Standard-length distribution (2-cm intervals) of all Louisiana red drum and spotted seatrout collected in this study are shown in Figure 2. Modes could be discerned in red drum length frequencies at 22 cm, 32 cm, 44 cm, and 56 cm. Comparison with other age-length information for red drum (Pearson 1929, Matlock 1984) indicates that these modes probably represent age classes I, II, III, and IV, respectively.

As might be expected in a species with an extended spawning period, age classes were not so clearly evident in length distributions of spotted seatrout. Nevertheless, apparent modes could be discerned at 10 cm, 26 cm, 34 cm, and 44 cm. Based on age-length data for spotted seatrout from the Gulf coast (Guest and Gunter 1958) and from the eastern U.S. coast (Mercer 1984), the latter three modes probably represent age classes II, III, and IV, respectively. It should be noted, however, that Pearson's (1929) back-calculated age-lengths for spotted seatrout indicate a slower growth rate than is indicated here, and if his estimates were followed these modes would more likely represent classes III through V.

Length frequencies during each season were also determined, and modes from these seasonal distributions were

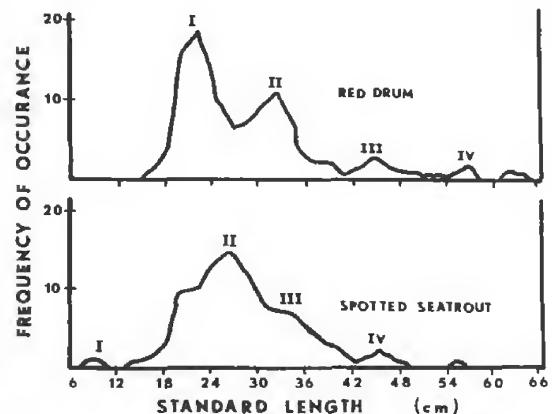


Figure 2. Length distribution of all Louisiana red drum and spotted seatrout collected in this study. Roman numerals indicate probable age class modes.

TABLE 3  
Regional condition factors  $\pm$  SE of red drum and spotted seatrout from Louisiana study areas 2–7 and from Texas.

Study Area	Red Drum		Spotted Seatrout	
	N	K <sub>c</sub>	N	K <sub>c</sub>
L2	(56)	2.05 $\pm$ .02	(64)	1.71 $\pm$ .02
L3	(49)	1.96 $\pm$ .02	(50)	1.35 $\pm$ .02
L4	(100)	1.94 $\pm$ .02	(296)	1.53 $\pm$ .01
L5	(43)	1.94 $\pm$ .02	(51)	1.49 $\pm$ .02
L6	(55)	2.04 $\pm$ .02	(54)	1.57 $\pm$ .01
L7	(11)	1.93 $\pm$ .04	(51)	1.61 $\pm$ .01
Texas	(37)	1.82 $\pm$ .02	(55)	1.41 $\pm$ .02

graphed to provide an indication of growth of each species during their first three years (Figure 3). The plots indicate red drum standard lengths to be 22 cm at age 1 and 38.5 cm at age 2, while the indicated standard lengths of spotted seatrout at these ages are 17.5 cm and 30 cm, respectively. The curvilinearity of the growth curves in Figure 3 suggests decreased growth rates in both species during winter.

Aging by scale analysis was hampered in both species by the presence of false annuli which were often difficult to distinguish from true annuli. Reading of red drum scales was further hindered by calcified deposits which tend to obliterate annuli as the fish grow. The consistency of our age determinations by scale reading was evaluated by randomly selecting 50 scale impressions of each species for re-examination. The second reading showed 76% agreement with the first reading for spotted seatrout, but only 32% for red drum.

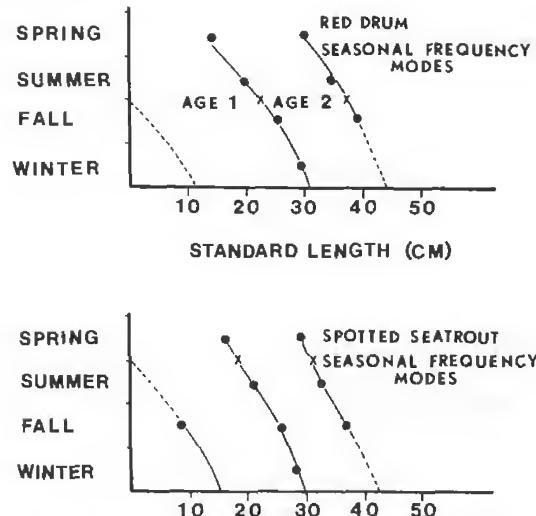


Figure 3. Yearly growth of red drum and spotted seatrout during their first three years as estimated from changes in seasonal length distribution modes. Closed circles indicate seasonal length distribution modes and dashed curves represent extrapolations of lines connecting the seasonal modes. Yearly increments from the y-intercept are represented by X.

Despite these inconsistencies, the mean lengths of each age class (as determined by number of annuli identified) were similar to the modal age-class lengths identified from length-frequency analysis (Table 4). Thus, scales can apparently be used to age spotted seatrout and red drum from Louisiana populations, but the procedure is difficult and time consuming.

Figure 4 shows Walford plots fitted to the year-end standard lengths for each species. The Walford equations for these plots are:

$$\text{red drum: } SL_{t+1} = 22 + 0.75 SL_t$$

$$\text{spotted seatrout: } SL_{t+1} = 17.5 + 0.71 SL_t$$

where  $SL_t$  and  $SL_{t+1}$  are standard lengths at ages t and  $t+1$ , respectively. Because the Walford plots are based on only two points, they should be used with caution. Moreover, growth of these species is probably not isometric over larger size ranges, so asymptotic weights estimated from these equations (Table 5) are probably underestimates. By comparison, Condrey et al. (1984) estimated an asymptotic length of 65.5 cm for Gulf coast spotted seatrout, while

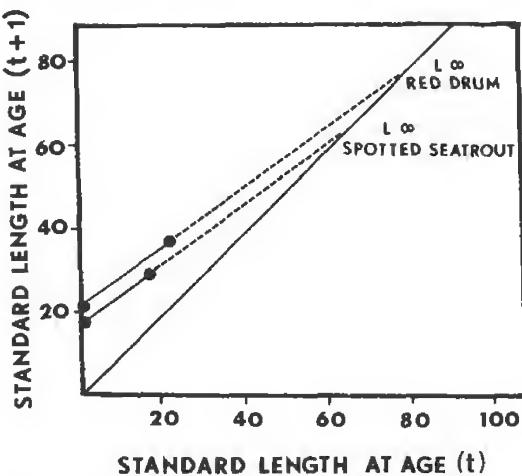


Figure 4. Walford's growth transformation for Louisiana red drum and spotted seatrout showing predicted asymptotic standard length ( $L_\infty$ ) for each species. Year-end standard lengths were obtained from Figure 3.

TABLE 4

Standard lengths (cm) of various age classes of red drum and spotted seatrout. MODAL LENGTH represents modes from standard length distributions in Figure 4. MEAN LENGTH (ANNULI) represents means of age groups identified by scale analysis. Estimated year-end lengths are from Figure 3.

AGE CLASS	Spotted Seatrout				Red Drum			
	I	II	III	IV	I	II	III	IV
MODAL LENGTH	—	26.0	34.0	44.0	22.0	32.0	44.0	56.0
MEAN LENGTH (ANNULI)	16.0	23.0	30.0	36.0	21.0	29.0	44.0	57.0
EST. YEAR-END LENGTH	17.5	30.0	—	—	22.0	38.5	—	—

TABLE 5

Von Bertalanffy equations for growth in length of red drum and spotted seatrout. Standard lengths (SL) in cm were derived from the von Bertalanffy equations with  $t_0$  assumed to be zero. Estimated weights were calculated from Louisiana weight-length regressions in Table 1.  $G_x$  = instantaneous growth coefficients.

Equation:	Red Drum			Spotted Seatrout		
	SL(cm)	W(g)	$G_x$	SL(cm)	W(g)	$G_x$
SL and W at age 1	22	210		17.5	87	
SL and W at age 2	38.5	1026	1.582	30.0	414	1.559
SL and W at age 3	50.9	2261	.790	38.9	879	0.753
SL and W at age 4	60.2	3635	.475	45.3	1366	0.441
SL and W at age 5	67.2	4941	.307	49.8	1798	0.275
Asymptotic SL & W	88.0	10593		61.3	3285	

Matlock (1984) estimated an asymptotic length of 106.5 cm for Texas red drum.

Despite some ongoing criticisms of its suitability (Knight 1968, Schnute 1981), the von Bertalanffy growth equation is still widely used in fisheries research, and its parameters are commonly implemented in yield-per-recruit analysis. For this reason, von Bertalanffy equations for growth in length were estimated from the Walford plots and tentatively used to project standard lengths for each species for ages 1 through 5 (Table 5). Predicted weights in Table 5 were obtained from the length-weight regressions for each species.

Yearly growth rates ( $G_x$ ) were calculated from the predicted year-end weight of each age group. The equation for yearly growth rate is:

$$G_x = (\ln W_i - \ln W_{i-1})/t$$

where  $W_i$  is weight in grams at age  $i$  and  $t$  is time in years (Bagenal and Tesch 1978). Yearly  $G_x$  values for each species decreased with increased age (Table 5) following the usual pattern for growth in fishes (Paloheimo and Dickie 1966). The  $G_x$  values indicate that red drum and spotted seatrout in Louisiana both show rapid growth rates, particularly during their first two years when average daily weight increases are close to 0.4% of body weight.

#### Sex Ratios and Mortality Rates

Analysis of sex ratios of various age classes ( $t$ -test,  $\alpha = 0.05$ ) showed that red drum sex ratios did not differ significantly from 50:50 over the entire length range collected (16–85 cm, SL). However, as standard length of spotted seatrout increased, there was a marked increase in the proportion of females (Figure 5). No male seatrout over 40 cm SL were collected. Similar increases in the proportion of females with increased size have been previously noted in Mississippi (Overstreet 1983a) and Florida (Tabb 1961) populations of spotted seatrout.

Annual mortality rates of these species can be estimated from the age frequency data if the following assumptions are made (Rounsefell and Everhart 1953): (1) ages have

been accurately deciphered; (2) natural and fishing mortality rates were uniform and constant during the time period covered by all age groups collected; (3) annual recruitment was constant over the time period represented by the sample; and (4) the age distribution of samples are representative of the true age distribution.

Although these assumptions could not be established with any degree of certainty, age frequencies from this study were used for preliminary estimations of total mortality for Louisiana populations of red drum and spotted seatrout. The method of Robson and Chapman (1961) was used to obtain estimates of the annual survival rate ( $s$ ) and the instantaneous mortality coefficient ( $Z$ ) for each species (Table 6). If male and female seatrout are considered separately, the estimated annual survival rate of female spotted seatrout (0.36) is approximately double that of males (0.16), a phenomenon which may have an important influence on the fishery. The estimated annual survival rate for red drum was also 0.16. Previous estimates of survival rates of these species tend to be somewhat higher than those obtained in this study. Tatum (1980) estimated annual survival for spotted seatrout populations in Alabama to be as high as 0.50, while Rutherford (1982) estimated an annual

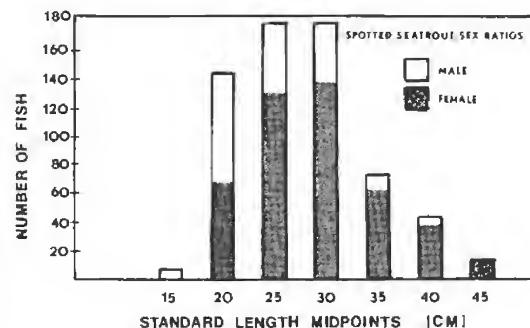


Figure 5. Changes in sex ratios of spotted seatrout with respect to body length.

TABLE 6

Annual survival rate ( $s$ ) and instantaneous mortality coefficient ( $Z$ ) for spotted seatrout and red drum as estimated from collected age frequencies. Postulated instantaneous fishing mortality coefficients ( $F$ ) and instantaneous natural mortality coefficients ( $M$ ) are based on the assumption that fishing mortality is 90% of total mortality (see text).

Species	$s$	$Z$	$F$	$M$
Spotted seatrout	0.32	1.139	1.025	0.114
Red drum	0.16	1.833	1.650	0.183

survival rate of about 0.25–0.30 for spotted seatrout in Everglades National Park. Matlock (1984) indicates an annual survival rate of 0.20 for Texas red drum populations.

We were unable to obtain estimates of fishing mortality rates versus natural mortality rates from our data. Natural mortality, however, tends to be relatively low in heavily exploited fish species, with fishing mortality usually comprising 85–90% of total mortality after such fishes attain vulnerable age (Rounsefell and Everhart 1953). Pauly's (1980) analysis of interrelationships between natural mortality, growth, and mean environmental temperature in 175 fish stocks also indicates that, for rapidly growing, long-lived species at temperatures characteristic of the Louisiana coast, natural mortality might be expected to be relatively low compared with fishing mortality. For this reason, the postulated instantaneous coefficients for fishing mortality ( $F$ ) and natural mortality ( $M$ ) of red drum and spotted seatrout in Louisiana (Table 6) are based on the assumption that mortality due to fishing is approximately 90% of total mortality in these species.

#### Population Numbers and Densities

If an estimate of the annual catch ( $C$ ) is available, the annual fishing mortality rate ( $f$ ) can be used to obtain an estimate of the total number of fish of vulnerable size in a population. The appropriate equation is  $N = C/f$ , where our postulated value for  $f$  is 0.9 ( $1-s$ ).

Approximately 450 thousand kg of red drum and 600 thousand kg of spotted seatrout are taken annually from Louisiana waters by commercial fishermen (Adkins et al. 1979, Perret et al. 1980). Since the recreational/commercial fishing ratio for both species has been estimated to be about 90:1 (Adkins et al. 1979), the total yearly harvest in Louisiana is about 40 million kg of red drum and about 55 million kg of spotted seatrout. Dividing the biomass values by the mass of the average fish taken in this study, we obtained the following estimates of total catch ( $C$ ) for each species:

red drum:  $C = 40 \text{ million kg} / 0.525 \text{ kg} = 76 \text{ million}$   
spotted seatrout:  $C = 55 \text{ million kg} / 0.385 \text{ kg} = 143 \text{ million}$ .

Inserting these values into the equation,  $N = C/f$ , the following preliminary estimates of total number of fish of

vulnerable age in Louisiana waters were obtained:

red drum:  $N = 76 \text{ million} / 0.756 = 100.5 \text{ million}$   
spotted seatrout:  $N = 143 \text{ million} / 0.612 = 233.7 \text{ million}$ .

It is important to note that these population estimates are conservative since they are based on the assumption that fishing mortality is relatively high compared to natural mortality for these species in Louisiana. If fishing mortality is low for these species, as was suggested by Iversen and Moffet (1962), population estimates would be almost an order of magnitude greater.

Barrett (1970) calculated the total water area of coastal Louisiana to be 1,376 million hectares. Thus, the expected average densities based on our preliminary estimates of population numbers in Louisiana are:

red drum:  $100.5 / 1.376 = 73.5 \text{ individuals per hectare}$ , and  
spotted seatrout:  $233.7 / 1.376 = 169.8 \text{ individuals per hectare}$ .

A 100-m net, such as was used to collect fish in this study, encloses an area of approximately 0.1 hectare when set in a semicircle from the shore. If many such sets are made, the average number of fish enclosed in each set should include about 7 red drum and about 17 spotted seatrout. Because our rotenone studies indicated that this netting procedure captures approximately 20% of the vulnerable-sized fish enclosed, an average set should capture 1.5 red drum and 3.4 spotted seatrout. These estimates are very close to our overall stratified sampling capture averages

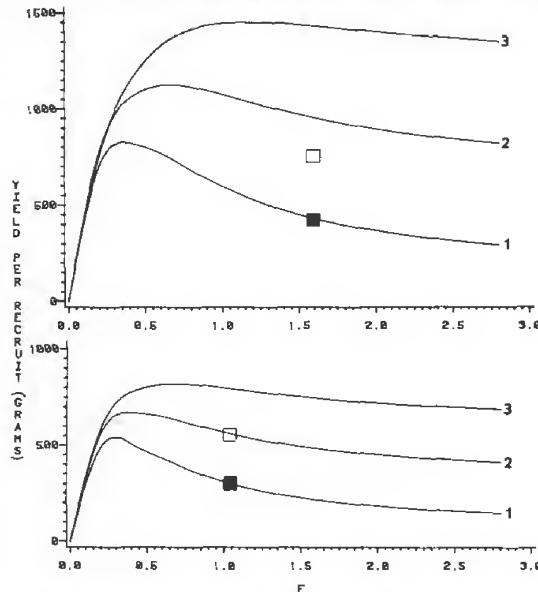


Figure 6. Yield curves (with  $t_c = 1, 2$ , and 3) as a function of  $F$  for red drum (top) and spotted seatrout (bottom). The closed squares indicate the current estimated position of the Louisiana fishery and the open squares indicate the estimated position if standard length at first capture were set at 30 cm.

from many sets at many diverse locations throughout the coastal region of Louisiana, an observation which tends to support our population estimates for these species.

#### *Yield-per-Recruit Estimates*

Beverton and Holt's (1966) tables of yield functions provide isolopleths of yield per recruit as a function of size at first capture and exploitation rate for a series of values of M/K ranging from 0.25 to 5.0. Using the estimated M/K values from the present study (M/K = 0.35 for spotted seatrout; M/K = 0.64 for red drum), and assuming the size at first capture to be 20 cm (no minimum recreational size limits for either species in Louisiana), the tables indicate yields of about 0.4 kg/recruit for red drum and about 0.3 kg/recruit for spotted seatrout when the exploitation rate is 0.9.

The Beverton-Holt (1966) model is particularly useful for assessing effects of changes in fishing effort or in size of first capture (Gulland 1969). The effect of increasing the size of first capture is graphically illustrated in Figure 6 in which yield-per-recruit curves as a function of the fishing mortality coefficient (F) are shown for various ages at first

capture ( $t_c$ ). The curves indicate that yield per recruit for red drum and spotted seatrout in Louisiana would be almost doubled by increasing the length at first capture to 30 cm (SL). By contrast, if the recreational/commercial fishing ratio for these species is about 90:1 (Adkins et al. 1979), a ban on commercial fishing would have minimal effects on yield per recruit.

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## Soil Characteristics of Four *Juncus roemerianus* Populations in Mississippi

Lionel N. Eleuterius

*Gulf Coast Research Laboratory*

John D. Caldwell

*Gulf Coast Research Laboratory*

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## SOIL CHARACTERISTICS OF FOUR *JUNCUS ROEMERIANUS* POPULATIONS IN MISSISSIPPI

LIONEL N. ELEUTERIUS AND JOHN D. CALDWELL

Botany Section, Gulf Coast Research Laboratory,

Ocean Springs, Mississippi 39564

**ABSTRACT** The physical and chemical characteristics of soil from four widely separated *Juncus roemerianus* populations in Mississippi tidal marshes are determined. The *J. roemerianus* populations studied are located in Grand Bayou, Salt Flats, Weeks Bayou, and Belle Fontaine marshes. Organic matter, pH, CEC, N, P, K, Ca, S, Mg, and Zn analyses are based on composite soil samples. The percentage of sand, silt, and clay of the marsh soils is determined along with soil water content from the four locations. Statistical analysis indicates which marshes are different for each soil characteristic tested. No appreciable amounts of organic matter are present in the soils from Grand Bayou and the Salt Flats, however, the soils of Weeks Bayou and Belle Fontaine marsh are highly organic. Magnesium is significantly different among all locations. Concentrations of P are greatest in the marsh soils from Grand Bayou and lowest in the Salt Flats. Greater values are recorded for organic matter, CEC, N, K, Ca, S, Mg, and Zn in the Weeks Bayou and Belle Fontaine marsh soils than are recorded for the soils at Grand Bayou and Salt Flats. The results of the soil analyses show that tidal marsh soils vary considerably in physical and chemical characteristics among locations, and *J. roemerianus* is able to grow well in a variety of soil types.

### INTRODUCTION

Tidal marshes in Mississippi form a thin border between the uplands and the Mississippi Sound. The marshes in Mississippi have been described by Eleuterius (1972) and Eleuterius and McDaniel (1978). These marshlands are dominated by the black needlerush *Juncus roemerianus* Scheele.

Tidal marsh soils along the Gulf Coast appear to be very diverse. Chabreck (1972) reported on the diversity of the vegetation, water, and soil characteristics of Louisiana marshlands. DeLaune et al. (1981) and Brupbacher et al. (1973) also reported on the chemical properties of marsh soils in Louisiana. The tidal marsh soils of the Florida Gulf Coast have been studied extensively by Coulter (1978a, 1978b) and Coulter and Gross (1975, 1977).

The relationships between the soils and the plant communities of Louisiana marshes have been studied by Palmisano and Chabreck (1972). They related chemical variables of the marsh soils with the distributions of major plant species in Louisiana. DeLaune et al. (1979) evaluated the relationship between soil properties and the biomass of *Spartina alterniflora*.

The objective of the present research is to compare soil characteristics from four populations of *J. roemerianus* located at widely separated locations along the Mississippi Coast and to determine the similarities and differences in the soils occupied by *J. roemerianus*.

### MATERIALS AND METHODS

Composite soil samples were collected from four populations of *J. roemerianus*. Locations of the Grand Bayou, Salt Flats, Weeks Bayou and Belle Fontaine populations of *J. roemerianus* are shown on Figure 1. The soil samples were

taken from the upper 5 to 15 cm of substrate and placed in plastic bags. Samples were frozen until the individual tests were performed. Soil water content, which is expressed as the ratio of the mass of water present in the sample to the mass of the dry sample and presented as a percent (Black 1965a), was obtained by oven drying the soil samples in seamless 180 ml cans at 105°C until dry. The marsh soils were analyzed by using standard methods (Black 1965b). Determinations were made of pH, cation-exchange capacity (CEC), organic matter, total nitrogen (N), acid-extractable phosphorus (P), potassium (K), calcium (Ca), sulfur (S), magnesium (Mg), and zinc (Zn). Individual chemical properties were compared among the four populations by analysis of variance (ANOVA) to determine statistical differences among the populations. The chemical properties which showed a significant difference were then subjected to Duncan's multiple range test, which indicated the population or populations that were statistically different, based on soil properties, from the other populations. The percentage of sand, silt, and clay contained in the soil was analyzed by granular metric methods, in which the sand values were obtained by sieving and the silt and clay values were obtained by hydrometer. These latter analyses were conducted by the Geology Section of the Gulf Coast Research Laboratory.

### RESULTS

Soil physical characteristics obtained from the four locations dominated by *J. roemerianus* are shown in Table 1. Based on the percentage of soil water from the different locations, it can be shown that the retention of water by the soils from Weeks Bayou and Belle Fontaine is greater than that by the soils from the Salt Flats and Grand Bayou marshes. No measurable amounts of organic matter are found in the soil samples taken from Grand Bayou and the

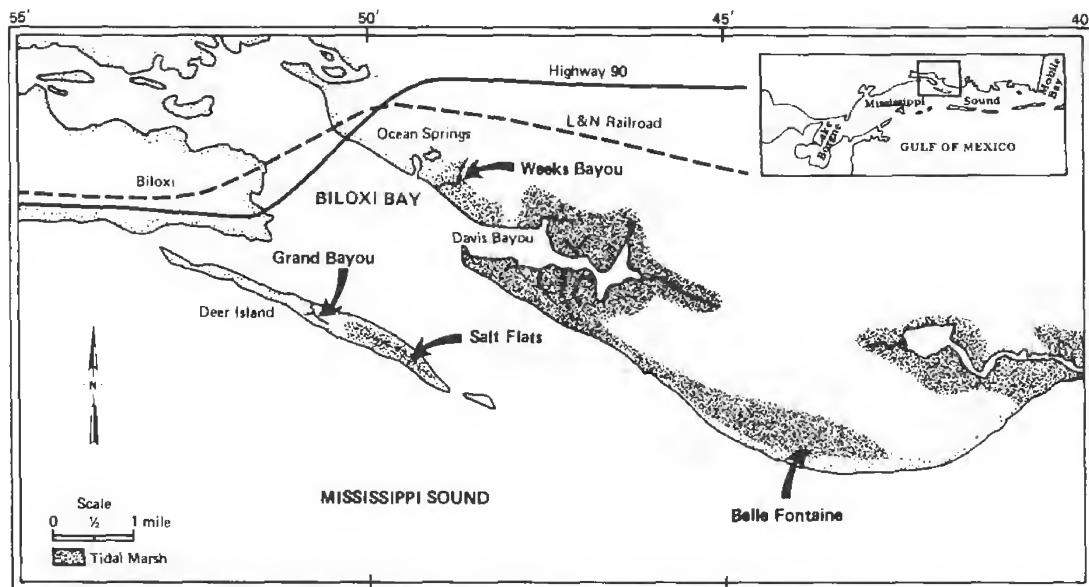


Figure 1. Locations of the four *Juncus roemerianus* populations studied are indicated by the arrows and names of the sites.

Salt Flats, but the organic matter in both the Weeks Bayou ( $\bar{x} = 21.2\%$ ) and Belle Fontaine ( $\bar{x} = 24.1\%$ ) soils is an important feature. The percent sand values show the Salt Flats soil has the greatest sand content and differs from all other locations. The Grand Bayou marsh soil, which is also high in sand content, also differs from the other locations. However, the relatively low sand values from Weeks Bayou and Belle Fontaine marshes do not show a difference. The silt and clay values, which are greater in the Weeks Bayou and Belle Fontaine marshes, do not differ. However, a difference occurs between these marshes and both the Salt

Flats and Grand Bayou marshes, which are not different.

The salinity of the soil water fluctuates frequently at these locations depending on the season, temperature, tidal pattern, and amount of precipitation (Eleuterius 1974). Soil water salinities are frequently observed as high as 300 ppt on the Salt Flats, but salinity values for soil water at the other three locations rarely exceeds 20 ppt.

The results of the Duncan's multiple range test on S, Ca, K, P, and pH do not show a difference between the Weeks Bayou and Belle Fontaine marshes; however, all the other combinations of marsh locations are different for these soil analyses (Table 2). The Grand Bayou and Salt Flats marshes are not different from each other and Weeks Bayou is not different from Belle Fontaine for Zn. Magnesium is different for all four locations. Organic matter, CEC, and N are not different for the Salt Flats and Grand Bayou marshes, however, all other combinations of marsh locations are different.

Although the values obtained from the soil chemical analyses vary greatly among the four locations, the Weeks Bayou and the Belle Fontaine marsh soils have greater concentrations of N, K, Ca, S, Mg, and Zn, and greater amounts of CEC and organic matter than are found in the marsh soils at Grand Bayou and the Salt Flats. The soils are more acidic in the marshes at Weeks Bayou and Belle Fontaine than those in the other two locations. However, the P concentration is greater in the soils from Grand Bayou than the other three locations. The Salt Flats soils have the lowest concentrations of P, and those at Weeks Bayou and Belle Fontaine are approximately the same.

TABLE I

Soil physical characteristics from four *Juncus roemerianus* locations. Mean values for percent soil water from two replicates. Mean values for the percent organic matter, sand, silt, and clay from six replicates. The organic matter values are the mean percentages for the total soil weight retained in the sieve series. Values in horizontal rows followed by the same capital letter are not significantly different ( $\alpha = 0.05$ ) according to Duncan's multiple range test.

Soil Physical Characteristics	Grand Bayou Marsh	Salt Flats Marsh	Weeks Bayou Marsh	Belle Fontaine Marsh	F(3,20)
Organic Matter (%)	0.0 A	0.0 A	21.2 B	24.1 B	6.59†
Sand (%)	71.1 A	82.8 B	3.3 C	4.0 C	557.55†
Silt (%)	18.1 A	13.1 A	41.3 B	42.1 B	7.59†
Clay (%)	10.8 A	4.1 A	34.2 B	29.8 B	31.93†
Soil Water (%)	29.2	19.4	143.9	123.3	

†Significant at the 0.05 level.

TABLE 2

Soil characteristics from four locations dominated by *Juncus roemerianus*. Values are the mean and standard deviation of three replicates. Values in horizontal rows followed by the same capital letter are not significantly different ( $\alpha = 0.05$ ) according to Duncan's multiple range test. Range values are in parenthesis.

Soil Analyses	Locations				$F_{(3,8)}$
	Grand Bayou Marsh	Salt Flats Marsh	Weeks Bayou Marsh	Belle Fontaine Marsh	
pH	7.5 ± 0.05 A (7.5–7.6)	6.8 ± 0.17 B (6.6–6.9)	6.1 ± 0.15 C (5.9–6.2)	6.3 ± 0.10 C (6.2–6.4)	75.78†
Cation-Exchange Capacity (meq/100g)	5.45 ± 0.15 A	2.91 ± 0.10 A	28.91 ± 2.60 B	25.46 ± 1.21 C	259.56†
Organic Matter (%)	0.58 ± 0.13 A	0.00 ± 0.00 A	18.88 ± 0.36 B	17.12 ± 1.03 C	1025.60†
Total Nitrogen (ppm)	433.0 ± 43.5 A	211.0 ± 10.0 A	5107.0 ± 298.1 B	7277.3 ± 392.8 C	600.75†
Phosphorus (ppm)	44.0 ± 3.4 A	4.0 ± 0.0 B	26.3 ± 5.1 C	26.0 ± 1.7 C	77.87†
Potassium (ppm)	278.0 ± 41.1 A	145.0 ± 7.5 B	529.0 ± 51.3 C	482.0 ± 30.8 C	72.19†
Calcium (ppm)	202.0 ± 0.0 A	78.7 ± 18.4 B	1355.3 ± 70.7 C	1266.0 ± 69.6 C	541.53†
Sulfur (ppm)	146.0 ± 19.0 A	61.7 ± 4.0 B	300.0 ± 0.0 C	300.0 ± 0.0 C	443.27†
Magnesium (ppm)	412.7 ± 10.5 A	241.0 ± 1.7 B	2327.3 ± 67.6 C	2098.7 ± 95.2 D	1045.08†
Zinc (ppm)	0.63 ± 0.05 A	0.43 ± 0.25 A	2.67 ± 0.58 B	2.30 ± 0.79 B	14.96†

†Significant at the 0.05 level.

#### DISCUSSION

In comparison to the marshlands located elsewhere along the northern Gulf of Mexico, no extensive, detailed studies have been conducted on the tidal marsh soils in Mississippi. However, the marsh soils along the Gulf Coast are shown to be very diverse in physical and chemical properties by comparing the works of Chabreck (1972), Patrick et al. (1977), DeLaune et al. (1979), DeLaune et al. (1981) in Louisiana, and Coulteras (1978a) in Florida. Although differences in the salt marsh vegetation have also been reported in the marshes of the northern Gulf of Mexico by Palmisano and Chabreck (1972) in Louisiana and Eleuterius (1972) in Mississippi, no clear relation to soil type was noted.

Water retention by soils depends largely on their physical structure. Tidal marsh soils that have a high sand content are more likely to lose soil water rapidly when exposed by low tides, than soils with a high organic content. Therefore, the structure, density, and other physical aspects of tidal marsh soils are important to all water relationships of plant species that grow in them. The soil characteristics reported in this study show that the marsh soils vary among the four locations; however, some similarities in the soils are also indicated. Soil pH values ranged from 5.9 to 7.6 for the four locations. These values are typical for tidal marsh soils and the range of our values corresponds to those reported by Chabreck (1972) for soil pH in saline marsh where *J. roemerianus* occurs in Louisiana.

Boyd (1970) showed that the concentrations of nitrogen and sulfur were directly related to the amount of organic matter found in aquatic soils. This relationship is also evident in our data. The greater concentrations of N and S found in the marsh soils of Weeks Bayou and Belle Fontaine correspond to greater organic matter content in the soils at

the same locations. Boyd (1970) and Coulteras and Gross (1975) stated that cation-exchange capacity of tidal marsh soils increases correspondingly with an increase in organic matter content. The higher the cation-exchange capacity of a soil, the greater the ability of the soil for trapping cations. Thus, cation-exchange capacity of tidal marsh soils varies directly with organic content (Boyd 1970, Coulteras 1978a). This direct relationship between cation-exchange capacity and organic matter is clearly shown in our data. The Grand Bayou and the Salt Flats soils are low in organic matter and these soils also have correspondingly lower cation-exchange capacity values than the higher organic soils of Weeks Bayou and Belle Fontaine. Farwell et al. (1979) also showed that sulfur compounds volatilized from soils at different moisture contents. Such volatilization obviously occurs in tidal marsh soils in Mississippi. Smith and DeLaune (1983) reported gaseous loss of nitrogen from Louisiana marshes. George and Antoine (1982) showed that temperatures, soil pH, and substrate concentrations affect denitrification.

Brubacher et al. (1973) reported large variations in the amounts of the elements magnesium, calcium, and potassium in the soils from the marshlands of Louisiana. The results from our data also show a wide range for these elements which varied as follows: Mg, 241 to 2327 ppm; Ca, 78 to 1355 ppm; K, 145 to 529 ppm. These fluctuations depend in part on daily and seasonal tidal levels, rainfall, and temperature.

Variations of soil phosphorus in marshlands have been shown by Brubacher et al. (1973). Palmisano (1970) and Palmisano and Chabreck (1972) have reported that lower phosphorus concentrations are associated with greater amounts of organic matter in the soil. Phosphorus is found

in variable concentrations at the different marshes in the present study. The greatest P concentrations are found in the soils at Grand Bayou, which are low in organic matter content. However, Weeks Bayou and Belle Fontaine marshes, which are high in organic matter content, have lower P concentrations than the Grand Bayou marsh. The reason for the low P concentrations found in the soils at the Salt Flats, which are also very low in organic matter, is not clear.

Zinc concentrations in marsh soils at the mouths of several rivers along the Atlantic Coast, which are dominated by *S. alterniflora*, have been reported by Dunstan and Windom (1975). They reported zinc concentrations in the sediments that ranged from 14.9 to 69.6 ppm. However, the Zn concentrations reported in the present study are considerably lower (0.43 to 2.67 ppm). The reason for the considerable differences in the amount of Zn between locations on the Mississippi Gulf Coast and those on the Atlantic Coast is not known. DeLaune et al. (1981) have shown that plant nutrients and heavy metals accumulate in salt marshes through sedimentation and accretion. However, Patrick et al. (1977) showed that redox affected nutrient availability in coastal wetlands. They found that although certain plant nutrients are present in marsh soils, their availability to certain marsh plants may be restricted. Waisel (1972) has pointed out that the nutrient uptake mechanism varies among halophytes. Eleuterius and Caldwell (1981) have shown that the absence of K, S, P, and Mg caused severe growth retardation and was essential to the growth of *J. roemerianus*. The absence of Ca, N, and Fe had a less severe effect on growth, indicating that *J. roemerianus* is physiologically peculiar. *J. roemerianus* may have a completely different physiological mechanism for uptake and utilization of nitrogen in comparison to what is presently known for most halophytes and terrestrial plants. It was not our purpose to compare nutrient concentration with plant growth or production. However, Valielas and Teal (1974) indicated that nitrogen availability was the most limiting and regulating factor in plant production on tidal wetlands.

Patrick and DeLaune (1976) showed the pattern of nitrogen and phosphorus utilization by *S. alterniflora*. Their work indicated that nitrogen was the most important nutrient limiting the growth of the grass *S. alterniflora*. A similar relationship for the rush *J. roemerianus* has not been established. Furthermore, Smith and DeLaune (1984) and Mendelsohn (1982) indicated that the rhizosphere and "deposits" found on the roots of *S. alterniflora* were related to the nutrition of the plant. They indicated that the area immediately around the root had different nutrient concentrations than the surrounding soil. "Deposits" on the roots were also found to have different concentrations of nutrients than the surrounding soil. No such "deposits" are found on the roots of *J. roemerianus*.

Our study shows that *J. roemerianus* is able to grow in a variety of marsh habitats that have different chemical and physical soil properties. Extensive monotypic and almost pure stands of *J. roemerianus* are formed over a wide range of soil types. In other local marsh areas *J. roemerianus* grows intermixed with other plant species. The reason for exclusion of other species from some populations is not known. The soils in the areas studied range from sand and clay, which are relatively low in organic matter and nutrients (Salt Flats and Grand Bayou), to the mud and peat soils which are high in organic matter and have correspondingly high concentrations of nutrients (Weeks Bayou and Belle Fontaine). The wide distribution of *J. roemerianus* in the tidal marshes of Mississippi and throughout the distributional range of the species is apparently related in part to the ability of the species to occupy a variety of soil types and nutrient regimes.

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The Effects of Weathered Crude Oil from the M/T Alvenus Spill on Eggs and Yolk-Sac Larvae of Red Drum (*Sciaenops ocellatus*)

George J. Guillen

*Texas Parks and Wildlife Department*

Dennis Palafox

*Texas Parks and Wildlife Department*

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## THE EFFECTS OF WEATHERED CRUDE OIL FROM THE M/T ALVENUS SPILL ON EGGS AND YOLK-SAC LARVAE OF RED DRUM (*SCIAENOPS OCELLATUS*)

GEORGE J. GUILLEN AND DENNIS PALAFOX

Texas Parks and Wildlife Department, Resource Protection Branch,  
Seabrook, Texas 77586

**ABSTRACT** The British tanker M/T ALVENUS ran aground 16.1 km south of Cameron, Louisiana, on 30 July 1984. An estimated 10,157 MT of Venezuelan crude oil were spilled into the Gulf of Mexico. Approximately 2,700 MT of the heavy viscous oil impacted beaches and an additional 1,360 MT remained in the subtidal areas of west Galveston Island, about 160 km southwest of the accident site. Red drum, which spawn in the Gulf of Mexico in the fall, could have been seriously impacted by oil concentrations potentially lethal to eggs or larvae. The impact of weathered crude oil on the survival, growth, and morphological development of red drum eggs and larvae was assessed in the laboratory. Equal numbers of eggs were randomly assigned to one of six treatments of weathered crude oil (control, 50, 100, 500, 1,000 and 2,000 mg/l) and observed through the yolk-sac stage. There were no differences in mean survival, length of surviving larvae, and frequency of morphological abnormalities among treatments ( $\alpha \leq 0.05$ ). In addition, the frequency of spinal deformity and abnormal mouth development was low in all treatments. The initial chemical composition of the fresh crude oil and the seasonally warm weather contributed to the natural degradation of the soluble toxic components.

### INTRODUCTION

The British oil tanker M/T ALVENUS ran aground 16.1 km south of Cameron, Louisiana, on 30 July 1984. An estimated 10,157 MT of Venezuelan crude oil were spilled into the Gulf of Mexico. The resulting surface slick drifted in a southwestern direction for 3 days before making landfall. The path of the slick passed the mouths of three coastal passes, Sabine Pass, Rollover Pass, and the Galveston Bay entrance. Approximately 2,700 MT of oil impacted beaches and an additional 1,360 MT remained in the subtidal areas of Galveston Island, about 160 km southwest of the accident site. In the heavily impacted areas of the west end of the island, submerged oil extended 6.0 to 15.3 m offshore and coated the bottom with a layer 15.2 to 20.3 cm deep.

The occurrence of the oil spill coincided with the spawning season of red drum (*Sciaenops ocellatus*). Red drum is a recreationally and commercially important species distributed along the Atlantic and Gulf of Mexico coasts of the U.S., ranging from New York to Texas. Red drum spawn along the Texas coast beginning in mid-August, peaking in late August and early September, and extending to November (Perret et al. 1980). Spawning usually occurs in or around mouths of passes and adjacent offshore waters (Perret et al. 1980). During the spawning season large adult red drum are sometimes numerous along the beachfronts (McEachron 1980). Larval and postlarval redfish occupying these habitats range in size from 4.0 to 12.0 mm SL (Pearson 1929, Sabins 1973, and Guillen 1983).

Based on the path of the surface slick, known spawning season, and the distribution of eggs and larvae, red drum could have been detrimentally impacted by the oil spill through various mechanisms. These mechanisms include physical coating, lethal toxicity, sublethal toxicity, and physiological incorporation (Moore and Dwyer 1974).

Laboratory toxicity tests have demonstrated that the embryonic and larval periods are the most sensitive stages in the life history of fishes (McKim 1977). Water soluble components of crude oil have been shown to be toxic to adult and juvenile estuarine organisms (Anderson et al. 1974). Results of experiments conducted on eggs and larvae of Pacific herring (*Clupea harengus*) have demonstrated that water soluble fractions of crude oil increase the occurrence of gross abnormalities and decrease the growth rate of newly hatched larvae (Smith and Cameron 1979). In addition, less obvious deleterious effects have been observed at the cellular level in Pacific herring larvae (Cameron and Smith 1980). Rabalais et al. (1981) reported higher mean mortality and gross abnormalities in red drum eggs and yolk-sac larvae exposed to concentrations of crude oil observed during the Ixtoc I oil spill.

The objective of this study was to evaluate the possible effects of weathered M/T ALVENUS crude oil on the early development of red drum. We define weathered crude oil as oil which remained on the bottom in subtidal and intertidal zones after initial landfall on 4 August 1985. The majority of exposed immature red drum would contact this form of oil during the peak spawning period in September. The acute toxicity and sublethal effects of the weathered crude oil were evaluated using a static bioassay on the eggs and resulting yolk-sac larvae of red drum.

### METHODS

Information on the chemical composition of the fresh and weathered crude oil was considered essential for understanding the possible mechanisms of induced mortality and sublethal effects. The cargo holds of the M/T ALVENUS contained two types of crude oil, Merey and Pilon. Crude oil samples were collected from the cargo holds of the M/T ALVENUS and from Jamaica Beach by Conoco Oil Company personnel (Figure 1). Chemical analyses were



Figure 1. Area affected by the M/T ALVENUS oil spill. (A = Jamaica Beach, B = Galveston seawall, C = Galveston Bay entrance, D = Roll-over Pass, E = Sabine Pass).

performed by the Conoco Refining Technical Services Laboratory of Ponca City, Oklahoma (Leeman 1984). The specific gravity at 15.5°C, total sulfur content, heavy metal content, and distillation fractions were determined for both types of fresh crude (ASTM 1984). Except for distillation fractions, the same parameters were measured on weathered oil obtained from Jamaica Beach.

Texas Parks and Wildlife Department (TPWD) personnel collected one surface water sample in the surf zone at Jamaica Beach on 7 August and 8 September 1984. The oil content of these samples was determined by the partition gravimetric technique (Rand et al. 1976).

Samples of weathered crude oil were collected along Galveston seawall by University of Texas Marine Science Institute and TPWD personnel on 7 August and 28 August 1984, respectively (Figure 1). The oil was analyzed using silica gel column chromatography for percent saturated hydrocarbons, aromatic hydrocarbons, nitrogen, sulfur and oxygen compounds, and asphaltenes (Parker 1984). Qualitative observations were made on the composition and quantity of individual compounds within the aromatic fraction using a Perkin Elmer model 910 gas chromatograph equipped with a flame ionization detector (Parker 1984).

A portion of the crude oil obtained on 28 August 1984 was used for the static bioassay (Peltier 1978). Exposure concentrations of 0, 50, 100, 500, 1,000 and 2,000 mg/l

crude oil were selected. Three replicate 5-liter McDonald jars containing synthetic seawater prepared from Instant Ocean<sup>1</sup> were used for each treatment concentration. These clear fiberglass cylindrical jars measured approximately 38.1 cm tall with a diameter of 14.3 cm. The oil was added to the water at 2000 hours on 17 September 1984. The salinity, temperature, and dissolved oxygen in all containers were 35 ppt, 26°C, and 6.8 mg/l, respectively. Air stones were used to gently aerate and circulate the water and oil.

Recently fertilized 1-hour-old eggs were obtained from spawning red drum maintained in captivity at the TPWD John Wilson Fish Hatchery at Flour Bluff, Texas. The salinity, temperature, and dissolved oxygen in spawning tanks were 36 ppt, 26°C, and 6.9 mg/l, respectively. Twenty-five eggs were randomly selected and placed into each container on 17 September 1984 between 2130 and 2230 hours. Constant overhead fluorescent illumination was provided and the room temperature was thermostatically maintained at 25°C. Salinity, water temperature, and dissolved oxygen were monitored in each container at 24, 48, and approximately 64 hours after introduction of the eggs. Qualitative observations of the amount of visible floating oil, number of unhatched eggs, and dead and deformed larvae were made. The bioassay was terminated and the yolk-sac larvae

<sup>1</sup>Reference to trade names does not imply endorsement.

were randomly removed between 0950 and 1315 hours on 20 September 1984, approximately 60 to 67 hours postfertilization and 36 to 43 hours posthatching. The number of live and abnormal live larvae were counted. Larvae were considered dead if the body was opaque and if no opercular and/or body movement was observed after tactile stimulation by a small needle. Larvae were considered abnormal if spinal curvature, incomplete mouth and gut development, or other gross deformities were observed. Notochord length (NL) of three randomly selected larvae from each container was measured with an ocular micrometer.

A Kruskal-Wallis one-way analysis of variance was used to test the null hypotheses that percent mortality, percent abnormality of surviving larvae, and mean lengths were equal for all treatments (Daniels 1978). A significance level of  $\alpha = 0.05$  was preselected before the analyses.

### RESULTS

The oil spilled from the M/T ALVENUS was a heavy viscous crude (Tables 1 and 2). For comparison, an outline of the typical constituents of crude oil, based on distillation fractions, is provided (Table 3) (Morrison and Boyd 1973). The two types of crude oil spilled, Merey and Pilon, exhibited relatively high specific gravities. Lighter alkanes and cycloalkanes were absent. Approximately 70% of the fresh crude oil was composed of insoluble high molecular weight asphaltenes (Tables 1 and 3). In addition, these crude oils contained a large fraction of aromatic hydrocarbons.

The weathered crude oil contained high concentrations of water and sand (Tables 2 and 4). The percentage of high molecular weight asphaltenes per unit of oil was slightly

TABLE 1

Physical and chemical properties of Merey and Pilon crude oil spilled from the M/T ALVENUS on 30 July 1984. Summary of analyses performed by Conoco laboratories.

Attribute/Chemical	Merey	Pilon
Specific gravity at 15.5°C	0.958	0.978
Total sulfur, wt %	2.5	2.7
Heavy metals, ppm		
Vanadium	265.0	265.0
Nickel	60.0	70.0
Copper	<0.5	<0.5
Fractional distillation, temperature cut range (°C)	% yield by weight	
C <sub>1</sub> –C <sub>5</sub> gases	0.10	—
37.8 – 85.0	1.49	—
85.0 – 193.3	3.96	—
193.3 – 232.2	3.12	3.84
232.2 – 265.5	3.92	3.26
265.5 – 335.0	10.88	10.72
335.0 – 385.0	8.91	9.37
385.0 – 418.3	6.20	6.46
418.3 – 515.5	14.09	15.60
515.5 +	47.35	50.80

higher in the late August beach sample, relative to the earlier beach sample. In addition, the percentage of total aromatic hydrocarbons per unit of oil had decreased

TABLE 2

Physical and chemical properties of weathered crude oil spilled from the M/T ALVENUS and collected from Jamaica Beach on 9 August 1984. Summary of analyses performed by Conoco laboratories.

Attribute/Chemical	Level
% wt	
Water	15.0
Solids	65.0
Oil	20.0
Analysis of oil component	
Specific gravity at 15.5°C	0.9745
% wt sulfur	2.6
Heavy metals, ppm	
Vanadium	280.0
Nickel	77.0
Copper	1.0

TABLE 3

Typical hydrocarbon constituents of crude oil.

Fraction	Distillation temperature (°C)	Carbon number
Gas	below 20	C <sub>1</sub> –C <sub>4</sub>
Petroleum ether	20–60	C <sub>5</sub> –C <sub>6</sub>
Ligroin (light naphtha)	60–100	C <sub>6</sub> –C <sub>7</sub>
Natural gasoline	40–205	C <sub>5</sub> –C <sub>10</sub> and cycloalkanes.
Kerosene	175–325	C <sub>12</sub> –C <sub>18</sub> and aromatics.
Gas oils	300–400	C <sub>16</sub> –C <sub>25</sub>
Residual oils – asphaltenes	above 400	Above C <sub>25</sub> , long chains attached to cyclic hydrocarbons. Molecular weight = > 20,000.

TABLE 4

Results of silica gel column chromatography conducted by University of Texas laboratories on the petroleum fraction of oil spilled from the M/T ALVENUS, and collected from Galveston Island seawall on 7 and 28 August 1984.

Component	Percent Composition	
	8.7-84	8-28-84
Sand and insolubles	40.70	52.00
Petroleum fractions		
Saturated hydrocarbons	14.83	12.84
Aromatic hydrocarbons	21.34	15.58
N, S, O compounds	6.50	4.86
Asphaltenes	16.60	15.17

slightly (Table 4). Based on qualitative observations of the gas-liquid chromatogram, low molecular weight aromatics such as benzene through phenanthrene were largely absent in the weathered crude oil. These observations and the increased level of sand and insolubles at progressively later dates indicated natural weathering processes were active during the spill.

Analyses of the fresh and weathered crude oils revealed high levels of vanadium (Tables 1 and 2). Vanadium content did not appear to decrease with weathering. This strongly indicated that vanadium compounds present in the weathered oil were fairly stable.

Surface water samples collected at the beach on 7 August and 8 September 1984 yielded oil levels of 1,190 mg/l and 43 mg/l, respectively.

Water quality parameters measured varied little throughout the experiment. Dissolved oxygen never fell below 6.2 mg/l in any container. Water temperature varied between 25 and 26°C. Salinity fluctuated between 34 and 37 ppt.

Live larvae and eggs were observed in all containers on 8 September 1984 at 1900 hours. Appreciable amounts of surface oil had accumulated in various containers of the 50, 100, 500, and 2,000 mg/l treatments (Table 5). On 9 September 1984 at 0735 hours, one to three dead larvae exhibiting spinal curvature were observed in replicates one and two of the 1,000-mg/l treatment. Dead and deformed larvae were also observed in replicate two of the 2,000-mg/l treatment and replicates two and three of the 1,000-mg/l treatment.

Mortality of red drum eggs and yolk-sac larvae varied erratically between treatments (Table 5). In addition, high mortality was observed in replicate one of the control exposure. No statistically significant differences in mortality occurred in any of the treatments. Visible sublethal effects were limited to abnormal spinal curvature and were infrequent and statistically insignificant across all concentrations

(Table 6). The size of the yolk-sac larvae ranged between 1.7 and 2.8 mm NL and averaged 2.3 mm NL. There were no significant differences in size of larvae among treatments (Table 7).

TABLE 5

Percent mortality of red drum eggs and larvae after a 64-h exposure to six concentrations of weathered crude oil spilled from the M/T ALVENUS. S denotes visible surface oil observed.

Concentration mg/l	Replicate			mean
	1	2	3	
0	60	4	0	21
50	16 <sup>s</sup>	20	32	23
100	24	0 <sup>s</sup>	32	19
500	0	24 <sup>s</sup>	24	16
1,000	68	24	32	41
2,000	40 <sup>s</sup>	40 <sup>s</sup>	16 <sup>s</sup>	32

TABLE 6

Percent incidence of spinal curvature in surviving red drum yolk-sac larvae after a 64-h exposure to six concentrations of weathered crude oil spilled from the M/T ALVENUS. S denotes visible surface oil observed.

Concentration mg/l	Replicate			mean
	1	2	3	
0	0	0	0	0
50	0 <sup>s</sup>	0	6	2
100	0	0 <sup>s</sup>	0	0
500	4	5 <sup>s</sup>	0	3
1,000	0	0	0	0
2,000	0 <sup>s</sup>	0 <sup>s</sup>	0 <sup>s</sup>	0

TABLE 7

Notochord length range (RG, mm) and mean notochord length (NL, mm) of surviving yolk-sac larvae after a 64-h exposure to six concentrations of weathered crude oil spilled from the M/T ALVENUS. Grand mean is denoted by  $\bar{N}L$ . S denotes surface oil observed.

Replicate	Concentration mg/l					
	0	50	100	500	1000	2000
1						
RG	2.0–2.3	1.7–1.9	2.4–2.6	2.5–2.8	2.2–2.6	2.3–2.5
NL	2.1	1.8 <sup>s</sup>	2.5	2.7	2.4	2.4 <sup>s</sup>
2						
RG	2.3–2.5	2.2–2.4	2.1–2.3	2.3–2.5	2.2–2.3	2.3–2.4
NL	2.4	2.3	2.2 <sup>s</sup>	2.4 <sup>s</sup>	2.2	2.4 <sup>s</sup>
3						
RG	2.3–2.4	2.1–2.4	2.2–2.5	2.4–2.5	2.2–2.3	2.3–2.4
NL	2.3	2.3	2.4	2.5	2.2	2.4 <sup>s</sup>
Total						
$\bar{N}L$	2.3	2.1	2.4	2.5	2.3	2.4

## DISCUSSION

The high mortality observed in one of the control replicates suggests that other factors, besides oil, may be affecting the survival of red drum eggs and larvae in these experiments. Hydrological variables monitored were well within the range necessary for optimum survival (Holt et al. 1981). Ammonia may have been a problem to larvae in oil-treated containers. Degradation of the oil by bacteria may have generated high concentrations of un-ionized ammonia. Concentrations as low as 0.55 mg/l of un-ionized ammonia have been shown to significantly increase mortality in larval red drum (Holt and Arnold 1983). However, low stocking densities and the use of eggs and yolk-sac larvae virtually eliminated the introduction of ammonia by metabolic end products and/or external food sources. Based on previous experience with the culture of red drum, the high mortality observed in the control replicates may have been caused by bacterial contamination (Holt and McCarty 1984).

The higher mean mortalities observed in the 1,000- and 2,000-mg/l treatments suggests that the oil may increase larval mortality at and exceeding these levels. However, the incidence of gross abnormalities was low in these containers. Based on our observations, the weathered crude oil exhibited low toxicity to red drum eggs and larvae. A static bioassay conducted with adult pinfish (*Lagodon rhomboides*) substantiates the relatively low toxicity of this weathered crude oil to estuarine fish (Spears 1984). The reported 48 hour LC<sub>50</sub> was 19,500 mg/l of weathered crude oil. However, adult fish are generally more tolerant to pollutants than egg and larval stages (McKim 1977).

The reduced toxicity observed at low treatment levels is related to the chemical composition of the weathered oil and the metabolism of aromatic hydrocarbons by the egg and larval stages of fish. Petroleum crude oil is a complex mixture of hydrocarbons and associated inorganic compounds. Each of these chemicals exhibits its own associated toxicity to aquatic organisms. The acute toxicities of many of these compounds have been determined for various species, but little information exists on their synergistic effects. There is general agreement that the acute toxicity of crude oil is positively correlated with the aromatic hydrocarbon content. Aromatics are generally more toxic than cycloalkanes which are in turn more toxic than paraffins. Within each of these hydrocarbon groups the smaller molecules are generally more acutely toxic. The toxicity of aromatic hydrocarbons increases with increasing molecular size from benzene to phenanthrene, although the 4- and 5-ring aromatics are not acutely toxic (Davis et al. 1984). However, these 4- and 5-ring polynuclear aromatic hydrocarbons, such as benzo( $\alpha$ )pyrene, are known carcinogens (Malins and Hodgins 1981).

The crude oil spilled from the M/T ALVENUS was a heavy viscous type. The majority of lighter, toxic alkanes and cycloalkanes were absent from the oils. However, at least 21% of the crude oil was composed of aromatic hydro-

carbons (Table 4). Based on qualitative observations of the gas-liquid chromatogram, the majority of these compounds were high molecular weight, water insoluble, polycyclic aromatic hydrocarbons (PAH). The majority of the water soluble and light hydrocarbons were probably lost during the initial 3 days of weathering at sea. These soluble phases usually include benzene and alkylbenzenes. However, the less soluble 2- and 3-ring aromatic compounds that remain are generally more acutely toxic (Anderson et al. 1974). As indicated by the gas-liquid chromatogram, the weathered crude oil did not contain a high percentage of these low molecular weight polycyclic aromatic hydrocarbons. Microbial and photochemical degradation at sea may partly account for this observation. Lee and Ryan (1983) reported that the half-lives of various PAHs were reduced to approximately 3 days during September (28°C) in a controlled microcosm experiment.

The structure of the red drum eggs and yolk-sac larvae may have also provided some protection against the adverse effects of petroleum hydrocarbons. Korn and Rice (1981) found that eggs of coho salmon (*Oncorhynchus kisutch*) were more tolerant of aromatic hydrocarbons than alewife or fry. They suggested that the chorion, the protective membrane of the egg, prevented the rapid uptake of aromatic hydrocarbons present in the water. The amount of yolk also influenced sensitivity because aromatic hydrocarbons were selectively partitioned into the yolk, thus reducing their availability to the embryo until yolk absorption.

The elevated level of vanadium observed in the fresh and weathered crude oil was evidently nontoxic. The elemental form of vanadium is insoluble in water. However, some compounds such as vanadium pentoxide are soluble and have induced chronic toxicity at levels above 0.08 mg/l in larval freshwater flagfish (*Jordanella floridae*) (Holdway and Sprague 1979). Analyses of the weathered crude oil suggests that vanadium compounds were relatively stable and resistant to chemical and/or biological degradation.

Long-term secondary effects to planktonic food items of larval red drum may have occurred but would be difficult to quantify. Dahl et al. (1983) reported that growth rates of copepod populations declined in controlled medium-scaled ecosystems when exposed to a 5 mm layer of surface crude oil.

The short-term effects of the M/T ALVENUS oil spill on red drum eggs and larvae were difficult to determine, but were probably limited to increased mortality caused by the physical coating of eggs and larvae in the field by floating heavy crude oil. The initial chemical composition of the fresh crude oil and the seasonally warm weather contributed to the natural degradation of the more soluble toxic components. Based on the low mortality, infrequency of gross deformities, and the similar sizes and developmental stages of all surviving larvae observed in the bioassay, the weathered oil could be classified as relatively nontoxic.

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Wilmer C. Stowe

*Lake Erie College*

James G. Gosselink

*Louisiana State University*

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## METABOLIC ACTIVITY OF THE EPIPHYTIC COMMUNITY ASSOCIATED WITH *SPARTINA ALTERNIFLORA*

WILMER C. STOWE<sup>1</sup> AND JAMES G. GOSSELINK<sup>2</sup>

<sup>1</sup>Lake Erie College, Painesville, Ohio 44060

<sup>2</sup>Department of Marine Science, Louisiana State University,  
Baton Rouge, Louisiana 70803

**ABSTRACT** Primary production and respiration rates were determined for two epiphytic communities associated with *Spartina alterniflora* Loisel., in the southwestern Barataria Bay area of Louisiana. The communities studied were: (1) a shoreline community and (2) a community 1.5 meters inland from the shoreline site. Annual mean net production and respiration rates for the shoreline community were  $25.8 \text{ mg C} \cdot (\text{m}^2 \text{ substrate area})^{-1} \cdot \text{h}^{-1}$  respectively; whereas the inland community showed corresponding rates of  $-3.3 \text{ and } -12.5 \text{ mg C} \cdot (\text{m}^2 \text{ substrate area})^{-1} \cdot \text{h}^{-1}$ , respectively. Thus, the shoreline community was a net contributor to system production; the inland community was an energy sink. The inland community was elevated 15 to 20 cm above the shoreline community, lacked the conspicuous filamentous algal growth common at the shoreline location, and had a significantly smaller diatom population. The role of epiphytes is speculated to be one of quality rather than quantity production.

### INTRODUCTION

Production by epiphytic algae has been found to vary in different environments. Using the  $^{14}\text{C}$  method, Allen (1971) found epiphytic production on submerged substrates to be  $600 \text{ g C} \cdot \text{m}^{-2} \cdot \text{y}^{-1}$  and  $71 \text{ g C} \cdot \text{m}^{-2} \cdot \text{y}^{-1}$  on emergent substrates. In the spring of the year, Jones (1980) using radioisotope technique observed a rate of  $24.8 \text{ mg C} \cdot (\text{m}^2 \text{ substrate area})^{-1} \cdot \text{h}^{-1}$  for epiphytes associated with *Spartina alterniflora* in a Georgia salt marsh. Jones (1968) found the epiphytes on *Thalassia testudinum* Konig. produced  $315 \text{ g C} \cdot \text{m}^{-2} \cdot \text{y}^{-1}$ , or about 35% of the host-epiphyte complex production. Studies by Sand-Jensen (1977) showed a significant reduction of host productivity as a result of epiphytosis. Penhale (1977) suggested that epiphyte shading could reduce host photosynthesis.

While the community structure of the microalgal population attached to (Stowe 1980, 1982) and beneath (Blum 1968, Sullivan 1978) the *S. alterniflora* canopy have been studied, only the report of Jones (1980) has investigated the productivity of the *S. alterniflora* epiphytic community. Others (Pomeroy 1959, Gallagher and Daiber 1973) have investigated sediment production beneath the grass canopy. This report describes the productivity and respiration of the epiphytic community associated with *S. alterniflora* in a salt marsh of the Barataria estuary, Louisiana.

### DESCRIPTION OF THE STUDY AREA

The Barataria estuary is an interdistributary, deltaic basin of the Mississippi River system (Russell 1936, Gagliano and van Beek 1970). It is a large ( $6,300 \text{ km}^2$ ), shallow series of bays and lakes flanked by marshes. The water is saline at the coast, grading through brackish to fresh at the upper reaches of the estuary (Day et al. 1973). Tidal cycles are diurnal rather than semidiurnal with a

0.3 m average amplitude (Baumann 1980).

Airplane Lake ( $N 29^{\circ}13.25'$ ,  $W 90^{\circ}06.18'$ ) was selected because a number of other ecological parameters were being studied at this site (Day et al. 1973). This marsh lies at a +5 cm relative to local mean water level. A natural levee rises from the shoreline, cresting about 1.5 to 3 m inland with an elevation of 15–20 cm. Maximum average water level of +20 cm occurs in September and a minimum level of –12 cm occurs in January. Baumann's inundation studies (1980) reported 260 marsh floodings per year with a mean duration of 17 hours per flood. The physical environment of the sampling area has been described further by Day et al. (1973) and Stowe (1980, 1982).

### MATERIALS AND METHODS

Twelve times between June 1970 and May 1971, *S. alterniflora* culms were collected from the Airplane Lake site. Twenty-four culms were collected immediately along the exposed edge of the marsh and an equal number from the crest of the natural levee 1.5 m inland from the shoreline site. The inland site was elevated about 15 cm above the shoreline site. The culms were severed at the sediment surface, placed in individual plastic bags and returned to the field laboratory under refrigeration.

Macroscopic algal biomass was determined from culm scraping, dried at  $80^{\circ}\text{C}$  for 24 hours, and weighed on an analytical balance. Microscopic algal density (almost all diatoms) was determined by the methods described by Stowe (1982).

Production of the epiphytic community was measured by a modification of the light-dark bottle method (Howard and Menzies 1969). Two bottom 10-cm lengths of the collected culms were placed in each of 24 BOD bottles. Water used for incubation was collected from Airplane Lake in a 20-liter carboy and allowed to settle for at least 2 weeks. The BOD bottles were filled by syphoning from

the middle of the carboy, allowing each bottle to overflow, replacing the volume in the BOD bottles approximately three times. Two uninoculated control bottles were also filled in the manner previously described.

The bottom 10 cm of the culms were used because structural studies indicated that 70% of the diatoms and practically all of the macroscopic algae were confined to this region (Day et al. 1973 and Stowe 1982). Gosselink et al. (1977) observed no net  $\text{CO}_2$  uptake by the bases of epiphyte-free, greenhouse-grown *S. alterniflora* and very low respiration rates. Therefore it was assumed that all  $\text{O}_2$  changes were the result of epiphytes.

Six shoreline and six inland bottles were incubated in a dark ice chest at ambient temperatures. Six other bottles with shoreline culms were incubated in direct sunlight while submerged in ambient temperature tap water in a large wash tub. Six bottles with inland culms were incubated in the shade of *Distichlis spicata*. Both light regimes approximated the natural conditions of the field. Incubation of these culms began by mid-morning within 1.5 hours of collection and was carried out for 2 hours.

Dissolved oxygen (DO) was determined from control bottles at the beginning of incubation and on the control and test bottles at the end of the 2-hour incubation period. Initially, DO determination was done by a modified Winkler titration method (Strickland and Parsons 1968). Later, DO was determined polarographically with the  $\text{O}_2$  sensor membrane fitting approximately one-third of the way down into the bottle. The water, during DO measurement, was stirred moderately with a magnetic stirrer. After determination of DO, the total water volume was measured to the nearest ml.

Net production and respiration were calculated as the difference between initial and final DO in the light and dark bottles, respectively, with control correction. Dissolved oxygen concentration was converted to mg carbon fixed or released by a modification of the method described by Strickland and Parsons (1968).

The average surface area of the culms was calculated by measuring the diameter of the lower portion of the culm and assuming it to be a cylinder 10 cm long. Fifteen culms collected from each site monthly were used in this determination.

#### RESULTS AND DISCUSSION

Four genera of macroscopic algae dominated the epiphytic community at the shoreline site. The macroscopic algae showed distinct seasonal variations in abundance (Figure 1) (Day et al. 1973). *Polysiphonia* sp. and *Bostriochia* sp. dominated from spring to fall. *Ectocarpus* sp. and *Enteromorpha* sp. dominated during the winter. These algae rarely occurred more than 50 cm inland. They were usually limited to a horizontal band 10 cm wide parallel to the shoreline. *Ectocarpus* sp. and *Enteromorpha* sp. grew on mud flats and other substrates as well as on *S. alterniflora*.

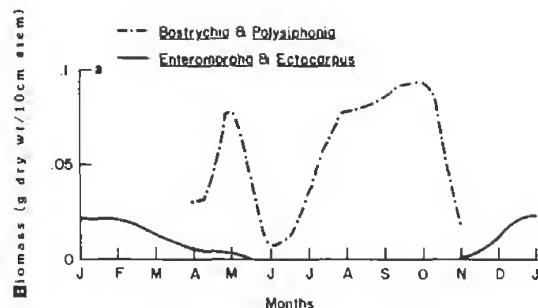


Figure 1. Seasonal biomass of the four dominant macroscopic algae.

The dominant microscopic epiphytes were diatoms. Diatoms occurred at densities of about  $1.8 \times 10^5$  per  $\text{cm}^{-2}$  of culm surface area and decreased in density with distance from the shoreline and height on the culm (Stowe 1982). They also varied seasonally with peak density on the bottom 10 cm of the host culm occurring in December–January (Stowe 1982). Further discussion of the epiphytic diatoms can be found in Stowe (1982).

Shoreline community mean metabolic rates were  $25.9 (\pm 12.4)$  and  $-19.6 (\pm 11.3)$   $\text{mg C} \cdot (\text{m}^2 \text{ substrate area})^{-1} \cdot \text{h}^{-1}$  for net production and respiration, respectively (mean  $\pm$  standard deviation). Inland community rates were  $-3.3 (\pm 9.5)$  and  $-12.5 (\pm 8.3)$   $\text{mg C} \cdot (\text{in}^2 \text{ substrate area})^{-1} \cdot \text{h}^{-1}$  respectively. Table 1 presents the F values calculated for separate one-way analyses of variance for shoreline and inland net production and respiration. Highly significant F values indicate that net production was significantly influenced by location and time of year. Respiration rate was not influenced by location; however, significant F values indicated that respiration varied seasonally. Culm counts of standing material indicated a density of  $220 \text{ m}^{-2}$  and  $360 \text{ m}^{-2}$  for the shoreline and inland communities, respectively. The average culm surface area for a bottom 10-cm section was  $27.9$  and  $27 \text{ cm}^2$ , respectively, for the shoreline and inland sites. Culm surface area per square meter of marsh surface was  $6124$  and  $9207 \text{ cm}^2$  for the lower 10-cm section of shoreline and inland culms.

TABLE 1  
F values for separate one-way ANOVA calculations  
for the following interactions.

Net Production	
shoreline vs inland	44.72**
shoreline vs sampling date	18.33**
inland vs sampling date	27.30**
Respiration	
shoreline vs inland	2.41
shoreline vs sampling date	32.47**
inland vs sampling date	30.44**

\*\*Significant at the .99 probability level.

Seasonal trends of net production with standard deviations are presented in Figure 2. Shoreline net production

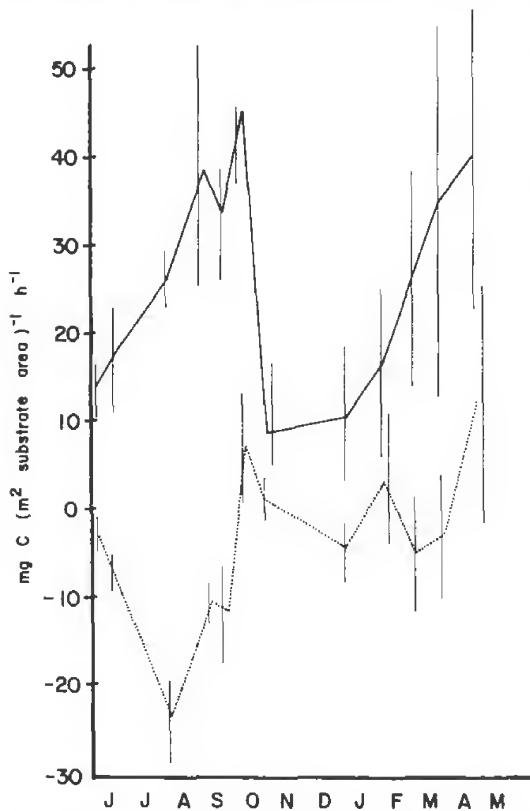


Figure 2. Seasonal variation in net production for the shoreline (—) and inland (···) communities.

shows a bimodal distribution with midspring and October–November peaks. This bimodality follows closely the seasonal biomass distribution of *Bostrychia* and *Polysiphonia* (Figure 1). Following the November decline, the production rate remains constant during the winter, then begins a spring rise. *Bostrychia* and *Polysiphonia* were seldom found in the inland community. Inland net production was positive during the late fall and early spring, but was negative the remainder of the year. The two communities had similar production rates during the winter when filamentous epiphytes were scarce. Even though epiphytic diatoms peak during the winter (Stowe 1982), they do not contribute significantly to net production. This observation is supported by the reports of several other authors (Penhale 1977, Pomeroy 1960, Sand-Jensen 1977, and Gosselink et al. 1977).

In contrast, the inland community was dominated by unicellular algae, predominately diatoms. Net production

was low and negative in the late summer when *S. alterniflora* stands were most dense reducing light penetration to the marsh floor. Conversely, net production became a positive contributor during the winter when the *S. alterniflora* canopy was more open. Shading and dessication were possible controlling factors of inland productivity. Since light could reach the shoreline community from the water side, low light was not considered to be a limiting factor here. The inland community with its elevation of 15–20 cm above the shoreline community was less frequently flooded, therefore more likely to have dessication stress. The work of Dawes et al. (1978) and unpublished work of one of the present authors (WCS) indicates that macroscopic estuarine algae recover rapidly from dessication; we are not certain that the same can be said for the unicellular forms.

Very high seasonal respiratory rates were calculated for the epiphytic community (Figure 3). At times these respira-

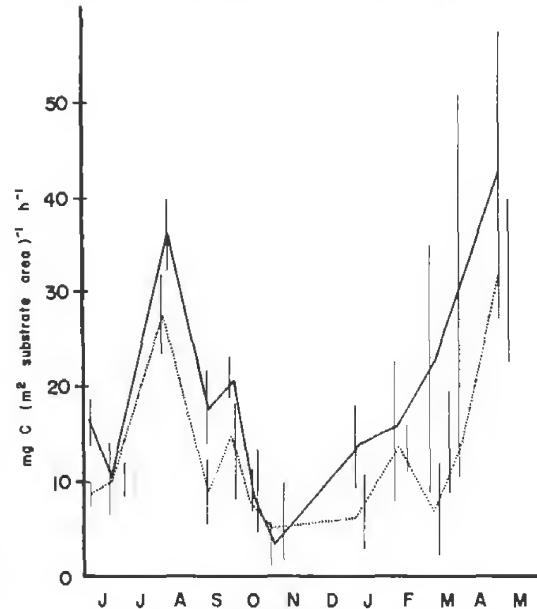


Figure 3. Seasonal variation in respiration for the shoreline (—) and inland (···) communities.

tion rates equaled or exceeded calculated net production values. Since there was no significant difference between the two communities and because the curves of Figure 3 are very similar, one might assume that the communities are similar. However, this is not the case (see description of the area and Stowe 1980, 1982). The shoreline macroscopic algae were often inhabited by invertebrates (such as small crustaceans and nematodes) which contributed to respiration. These herbivores reached maximal levels during peak net production. Contributors to greater respiration rates were the larger bacterial (Hood and Colmer 1971), fungal,

and meiofaunal (Meyers et al. 1970) communities which have been observed inland. These communities, although different, are sufficiently dense to give similar rates. The communities had similar respiration rates per substrate area. The rate per marsh surface area was significantly higher inland because of the greater culm density.

Metabolic averages did not present a complete picture of this community. High variability was a significant characteristic of these communities (note standard deviations in Figures 2 and 3). Variation in colonization among culms was shown by large standard deviations in the calculated metabolic rates. The calculated standard deviations in this study were often greater than half the corresponding mean values. These large deviations should be expected when considering the patchy distribution of macroscopic algae.

Grazing impact, while not assessed, could be significant. During the spring and fall, amphipod populations were concentrated in the epiphytic macroalgal masses (personal observation) and were present in much larger numbers than at any other time. R. E. Condrey (personal communication) had observed several other types of crustaceans grazing in the epiphytic algal masses. These herbivore maxima occurred during peak net production. While we are convinced that the November production and biomass decline was related to seasonal lowering of the water level (Stowe 1982), the decline of *Bostrychia* and *Polysiphonia* in May

was not so easily attributed to water level fluctuation. Perhaps the observations of Cattaneo (1983) in Canada are applicable and grazers were responsible for the May decline.

Jones (1980), working on Sapelo Island, Georgia, in early April, calculated an epiphytic production of  $24.8 \text{ mg C} \cdot (\text{m}^2 \text{ substrate area})^{-1} \cdot \text{h}^{-1}$  with a range of 15.3 to 45.5. Since Sapelo Island is a little farther north than Barataria Bay, their early April could be comparable to our late March. Our late March net production average was  $25.4 \text{ mg C} \cdot (\text{m}^2 \text{ substrate area})^{-1} \cdot \text{h}^{-1}$  ( $s = 13$ ). Considering the differences in techniques used and the areas studied, these results are remarkably similar. On this basis, it is tempting to speculate that these results have broader application than just to the Louisiana coast.

Initially the authors thought of the salt marsh *S. alterniflora* as a massive substratum for production of epiphytes. This was not true in Airplane Lake. In this study, net epiphytic productive contribution was limited to a narrow active band paralleling the shoreline. Inland from this band the epiphytic community was an energy sink. Thus epiphytic contribution to total marsh production was low (Day et al. 1973). Mason and Bryant (1975) found a freshwater epiphytic community to be a richer source of total nitrogen and phosphorous than the nearby sediments. Perhaps the role of the epiphytic community is one of quality production rather than quantity.

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Lionel N. Eleuterius

*Gulf Coast Research Laboratory*

John D. Caldwell

*Gulf Coast Research Laboratory*

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## SOIL CHARACTERISTICS OF *SPARTINA ALTERNIFLORA*, *SPARTINA PATENS*, *JUNCUS ROEMERIANUS*, *SCIRPUS OLNEYI*, AND *DISTICHLIS SPICATA* POPULATIONS AT ONE LOCALITY IN MISSISSIPPI

LIONEL N. ELEUTERIUS AND JOHN D. CALDWELL

Botany Section, Gulf Coast Research Laboratory,  
Ocean Springs, Mississippi 39564

**ABSTRACT** Soil characteristics from five adjacent monotypic zones or different populations of tidal marsh plants are determined. Populations of *Spartina alterniflora*, *Spartina patens*, *Juncus roemerianus*, *Scirpus olneyi*, and *Distichlis spicata* located in Graveline Bay marsh, Mississippi, are studied. Slight elevational differences between the plant populations exist. The aerial biomass for each plant population is different based on seasonal determinations. Soil pH, organic matter, N, P, K, S, Zn, Ca, and Mg concentrations are based on analyses of seasonal composite soil samples. Analyses of soil water samples are used to determine water content, salinity,  $\text{PO}_4$ , and  $\text{NH}_3$ . The soil characteristics are highly variable within and among populations. Some soil properties are significantly different, while others are not. These results reflect the complex patterns in the physical and chemical soil characteristics among the salt marsh plant populations studied; however, they may not completely account for the differences in standing crop or the sharp delineation between plant zones.

### INTRODUCTION

The occurrence of plant populations within salt marshes is controlled by varying ecological factors. The dominant ecological factors which control plant zonations are salinity (Bourdeau and Adams 1956) and tidal inundation (Hinde 1954); however, other factors, such as the physical and chemical characteristics of the soil, may also be important. Jackson (1952) reported on edaphic and elevational factors which affect the distribution of tidal marsh plants.

The composition of salt marsh plant communities have been reported on the Atlantic and Gulf Coasts. These plant communities may be composed of two or more plant populations. Adams (1963) described the composition of salt marsh communities of North Carolina, and Penfound and Hathaway (1938) reported on the plant communities of the southeastern Louisiana marshlands. Eleuterius (1972) and Eleuterius and McDaniel (1978) have described the marshes in Mississippi.

Tidal marsh soils are very diverse along the coastline of the northeastern Gulf of Mexico. The tidal marsh soils of the Florida Gulf Coast have been studied extensively by Coulas (1978a, 1978b), and Coulas and Gross (1975, 1977). Chabreck (1972) reported on the diversity of the vegetation and the water and soil characteristics of Louisiana marshlands. Brubacher et al. (1973) have also reported on the chemical properties of marsh soils in Louisiana. However, no detailed or extensive work has been done on the tidal marsh soils of Mississippi.

Relationships between marsh plant communities and soils in Louisiana have been studied by Palmisano (1970). Palmisano and Chabreck (1972) have also reported on the interrelationships between the chemical variables of marsh soils and the distribution of major plant species in Louisiana marshes.

This study was initiated to compare the soil characteristics in one general location where monotypic stands or populations of several major tidal marsh plant species occur. Graveline Bay (Figure 1) is a closed marsh system in which the only exchange of water is through the constricted mouth of Graveline Bayou. This marsh system was selected because the salt marsh species, which form extensive monotypic zones, are in close proximity to one another and because the habitats of these various populations are approximately at the same elevation. The five populations are: *Spartina alterniflora* Loisel., *Spartina patens* (Ait.) Muhl., *Juncus roemerianus* Scheele, *Distichlis spicata* (L.) Greene, and *Scirpus olneyi* Gray.

### MATERIALS AND METHODS

Composite soil samples were collected seasonally from each of five salt marsh plant populations in Graveline Bay marsh. Three soil samples were collected from 5 to 15 cm below the soil surface, combined, and placed in plastic bags. The samples were frozen until chemical analyses were performed by standard procedures (Black 1965). These seasonal composite soil samples were analyzed for soil pH, organic matter content, total nitrogen (N), acid-extractable phosphorus (P), potassium (K), sulfur (S), zinc (Zn), calcium (Ca), and magnesium (Mg). Salinity, orthophosphate ( $\text{PO}_4$ ), and ammonia nitrogen ( $\text{NH}_3$ ) analyses were conducted on the soil water from the seasonal composite soil samples. The soil water was removed from the soil samples by vacuum and analyzed in the water analysis laboratory at the Gulf Coast Research Laboratory. Soil samples were also analyzed for water content seasonally from the five tidal marsh populations. Soil water content is expressed as the ratio of the mass of water present in the sample to the mass of the dry sample, and is presented as a percent (Black 1965). All samples were oven dried in seamless 120-ml cans at 105°C for 48 hours. Preliminary determinations

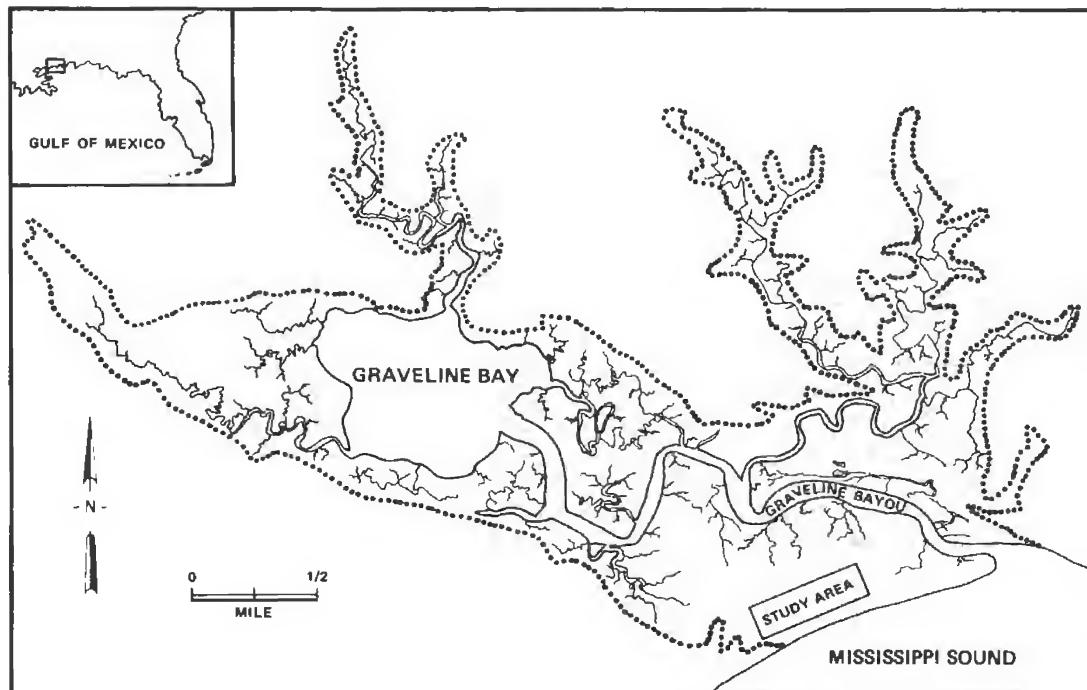


Figure 1. Map showing general location of plant populations studied in Graveline Bay marsh. Dotted line delineates marsh area.

indicated that a single seasonal measurement was adequate to approximate these analyses.

An analysis of variance (ANOVA) test was used to determine if a statistical difference existed among the five plant populations for each of the measured soil variables. A Duncan's multiple range test was then used to determine which of the measured soil variables was different among the plant populations.

Elevational data for the plant populations in Graveline Bay marsh were made during an extremely high tide in which the marsh surface was completely covered. Tidal height measurements were taken from the water surface to the soil surface to determine the relative elevation of the

plant populations to one another. Statistical analyses were used to determine differences in elevations of the populations.

Three 0.125-m<sup>2</sup> quadrat samples of the aerial portion of plants were collected seasonally from each of the five salt marsh plant populations. Plant material was oven dried at 105°C for 24 hours.

#### RESULTS

The standing crop values for each of the five different populations at Graveline Bay are shown in Table 1. The winter samples are shown to have the lowest standing crop values in all plant populations. However, the greatest values

TABLE 1  
Seasonal comparisons of aerial dry mass values (g) of the dominant species in the five plant populations.  
Values represent the mean and standard error of the mean for three samples.

Plant Populations (species)	Autumn	Winter	Spring	Summer
<i>D. spicata</i>	192.3 ± 2.9	167.0 ± 6.5	180.3 ± 7.0	219.3 ± 8.3
<i>J. roemerianus</i>	616.2 ± 25.9	490.0 ± 100.3	712.0 ± 21.2	579.7 ± 40.5
<i>S. alterniflora</i>	300.2 ± 17.0	177.0 ± 18.6	245.7 ± 24.2	225.0 ± 20.1
<i>S. patens</i>	330.4 ± 46.2	218.7 ± 21.0	543.0 ± 38.7	384.3 ± 36.3
<i>S. olneyi</i>	219.3 ± 13.7	131.7 ± 11.3	268.5 ± 21.8	213.7 ± 4.2

recorded show that peak aerial plant mass is obtained in the spring for *J. roemerianus* (712.0 g), *S. patens* (543.0 g), and *S. olneyi* (268.5 g). The greatest aerial biomass for *D. spicata* (219.3 g) is recorded in summer, and the greatest value for *S. alterniflora* (300.2 g) occurs in autumn. Comparison of these data clearly shows that *J. roemerianus* has almost twice the standing crop as *S. alterniflora* and *S. patens*, and the standing crop of *D. spicata* is similar to that of *S. olneyi*. Very little seasonal variation occurs in the *D. spicata* population in contrast to fluctuations in the other plant populations.

Elevation varies in the study area from 0.0 to 7.0 cm over the entire area of the five populations and averages 2.8 cm. Comparison of elevational data among the five plant populations in Graveline Bay marsh discloses that the highest elevation is found in the *D. spicata* population. The differences in the elevations among the plant populations show that *J. roemerianus*, *S. alterniflora*, *S. olneyi*, and *S. patens* occur at mean elevations below the *D. spicata* population of only 2.1, 2.2, 3.3, and 4.6 cm, respectively. However, statistical analysis on the elevational data indicate that differences exist among some populations. The *D. spicata* population is different from all other populations (Figure 2). The populations of *J. roemerianus*, *S. alterniflora*, and *S. olneyi* do not differ from each other; however, the results also indicate that the *S. olneyi* population is not different from the population of *S. patens*.

Soil water content varies throughout the year in relation to tidal action and precipitation. The lowest soil water content values ( $\bar{x} = 43.2\%$ ) occurred in the plant population dominated by *D. spicata* (Table 2) and remained relatively low throughout the year. Soil water content values from other plant populations ranged from a low of 63.5% in autumn for the *S. patens* dominated population, to a high of 221.2% for the *S. alterniflora* population in spring. Soil water content values from the populations dominated by *J. roemerianus*, *S. alterniflora*, *S. patens*, and *S. olneyi*,

show some variation among the populations, as well as from season to season; however, there appears to be no consistent pattern except for generally lower water content values during winter. Statistical analysis on the soil water content shows that differences exist among these populations.

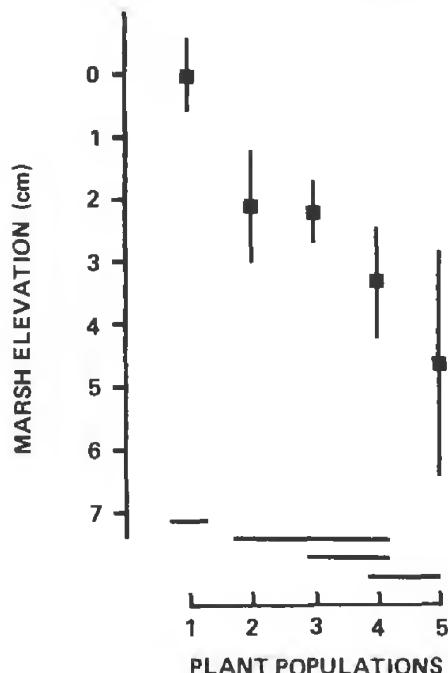


Figure 2. Elevational mean values for plant populations at Graveline Bay marsh. Plant populations: 1-*Distichlis spicata*, 2-*Juncus roemerianus*, 3-*Spartina alterniflora*, 4-*Scirpus olneyi*, 5-*Spartina patens*. Vertical line indicates 95% confidence interval. Horizontal lines over plant populations indicate significant difference ( $\alpha = 0.05$ ) from the Duncan's multiple range test.

TABLE 2

Soil water content, salinity, orthophosphate and ammonia nitrogen taken from five salt marsh plant populations at Graveline Bay marsh. Four seasonal values recorded for each analysis are combined and presented as the mean and standard error of the mean for the individual plant populations. Soil water content values represent the percentage of water in the soil sample on a dry-mass basis. Means in vertical columns followed by the same capital letters are not significantly different ( $\alpha = 0.05$ ) according to Duncan's multiple range test.

Plant Populations (Species)	Soil Water Content	Salinity (ppt)	Orthophosphate ( $\mu\text{g-at P/L}$ )	Ammonia Nitrogen ( $\mu\text{g-at N/L}$ )
<i>D. spicata</i>	43.2 $\pm$ 5.5 A	12.0 $\pm$ 1.5	28.32 $\pm$ 13.75	523.01 $\pm$ 306.95
<i>J. roemerianus</i>	151.6 $\pm$ 21.0 B	15.5 $\pm$ 1.1	25.47 $\pm$ 17.21	812.34 $\pm$ 547.73
<i>S. alterniflora</i>	153.8 $\pm$ 25.5 B	12.8 $\pm$ 0.4	7.80 $\pm$ 2.45	371.85 $\pm$ 42.35
<i>S. patens</i>	100.4 $\pm$ 11.4 A,B	12.0 $\pm$ 0.4	9.41 $\pm$ 6.39	283.75 $\pm$ 53.00
<i>S. olneyi</i>	113.4 $\pm$ 20.0 B	12.5 $\pm$ 1.1	2.52 $\pm$ 2.11	193.25 $\pm$ 64.04
F(4,16)*	4.655†	1.513	0.918	0.547

\*F value from the one-way analysis of variance.

†Significant at the 0.05 level.

Results of the Duncan's multiple range test indicate that the *S. patens* population did not differ from the other populations. However, the *D. spicata* population is different from the populations of *J. roemerianus*, *S. alterniflora*, and *S. olneyi*.

Soil water salinity fluctuates in the salt marsh with the amount of tidal flooding, evaporation, and precipitation. Seasonal soil water salinity samples show minor variations among the plant populations during each season, however, there is no statistical difference (Table 2). The greatest soil water salinity values are generally obtained in the summer and the lowest values occur in the winter. Soil water salinity values range from 7 to 15 ppt in the *D. spicata* population and from 12 to 18 ppt in the *J. roemerianus* population. The salinities in the populations dominated by *S. alterniflora*, *S. patens*, and *S. olneyi* range from 12 to 14 ppt, 11 to 13 ppt, and 9 to 15 ppt, respectively.

Orthophosphate and ammonia nitrogen concentrations vary greatly not only among the plant populations sampled during the same season, but also among the seasons for the individual plant populations. Orthophosphate concentrations vary from 3.67 µg in autumn to 74.90 µg in summer for the *D. spicata* population and from 2.47 µg in winter to 84.93 µg in spring for the population dominated by *J. roemerianus*. Concentrations in the *S. alterniflora* population range from 2.51 µg in winter to 15.82 µg in summer. The *S. patens* and *S. olneyi* populations range from 0.00 µg in summer to 31.12 µg and 9.83 µg, respectively, in spring. Ammonia nitrogen concentrations for the *D. spicata* and *S. patens* populations range from 53.73 µg and 161.54 µg,

respectively, in summer to 1554.00 µg and 411.60 µg, respectively, in winter. The ammonia nitrogen in the populations of *S. alterniflora* and *S. olneyi* ranges from 261.96 µg and 34.58 µg, respectively, in spring to 478.00 µg in winter for *S. alterniflora* and 392.08 µg in autumn for *S. olneyi*. The ammonia nitrogen in the *J. roemerianus* population ranges from 122.64 µg in summer to 2706.25 µg in autumn. Although the variations in PO<sub>4</sub> and NH<sub>3</sub> are large, there are no statistical differences (Table 2).

No statistical differences are indicated by the ANOVA test among the plant populations for the soil elements K, S, Zn, Ca, and Mg (Table 3). However, there is a difference among the plant populations for the variables pH, N, P, and organic matter content.

Soil pH values are greater in the *D. spicata* plant population than in all other populations. Statistical comparison of the *D. spicata* population to all others shows it to be different. The populations of *J. roemerianus*, *S. patens*, and *S. alterniflora* are similar in soil pH and do not differ statistically. However, the soil pH values of the *S. alterniflora* population are also similar to those in the population of *S. olneyi*. And the values of these two populations are not statistically different. The range and mean pH values are shown in Table 3, along with the statistical relationships between the five plant populations.

Total nitrogen concentrations and the amount of organic matter in the soils are considerably lower in the *D. spicata* population than in all other plant populations. Phosphorus concentrations in the *D. spicata* population are greater than concentrations in the *J. roemerianus* population and the

TABLE 3

Chemical characteristics of composite soil samples taken from five salt marsh plant populations at Graveline Bay marsh. The four seasonal values recorded for each soil analysis were combined and presented as a mean and standard error of the mean for the individual plant population. Means in vertical columns followed by the same capital letters are not significantly different ( $\alpha = 0.05$ ) according to Duncan's multiple range test. Range values are in parenthesis.

Plant Populations (species)	pH	Organic Matter (%)	N (ppm)	P (ppm)	K (ppm)	S (ppm)	Zn (ppm)	Ca (ppm)	Mg (ppm)
<i>D. spicata</i>	(7.4–7.7) 7.5 A $\pm 0.1$	3.9 A $\pm 0.4$	1446 A $\pm 133$	189 A $\pm 24$	285+ $\pm 0$	300+ $\pm 0$	5.19 $\pm 0.74$	1616 $\pm 230$	1420 $\pm 113$
<i>J. roemerianus</i>	(5.7–6.2) 6.0 B $\pm 0.1$	9.7 B $\pm 0.9$	4574 B $\pm 858$	133 B $\pm 11$	285+ $\pm 0$	300+ $\pm 0$	5.69 $\pm 0.89$	1372 $\pm 225$	2694 $\pm 465$
<i>S. alterniflora</i>	(4.6–6.4) 5.6 B,C $\pm 0.4$	10.1 B $\pm 0.5$	4494 B $\pm 529$	74 C $\pm 5$	285+ $\pm 0$	300+ $\pm 0$	6.81 $\pm 0.48$	1044 $\pm 143$	2167 $\pm 305$
<i>S. patens</i>	(5.5–6.9) 6.0 B $\pm 0.3$	10.4 B $\pm 0.2$	4204 B $\pm 522$	76 C $\pm 2$	285+ $\pm 0$	300+ $\pm 0$	7.73 $\pm 0.67$	1084 $\pm 66$	2106 $\pm 92$
<i>S. olneyi</i>	(3.7–6.3) 4.8 C $\pm 0.5$	8.7 B $\pm 1.3$	4089 B $\pm 986$	67 C $\pm 3$	285+ $\pm 0$	300+ $\pm 0$	7.48 $\pm 0.54$	1080 $\pm 208$	1948 $\pm 371$
F <sub>(4,15)</sub>	8.767†	12.376†	3.761†	17.835†	0.000	0.000	2.650	1.794	2.230

†Significant at the 0.05 level.

concentrations of phosphorus in the soils of these two populations are greater than those of the areas supporting the other plant populations. The populations of *S. patens*, *S. alterniflora*, and *S. olneyi* do not differ from each other in the concentration of soil phosphorus. No differences in soil sulfur and potassium concentrations are found among the five plant populations. The concentrations for the soil elements Mg, Ca, and Zn show variation among the plant populations, although no statistical differences are noted.

#### DISCUSSION

Variations in the soil properties of salt marshes have been studied along the Gulf Coast in Florida (Coulter and Gross 1977) and Louisiana (Chabreck 1972); however, the soils of the marshlands of Mississippi have not been adequately surveyed. Plant zonation in salt marshes has been studied along the Atlantic and Gulf coasts; however, the relative importance of different environmental factors, such as salinity, tides, elevation, and soil characteristics affecting the zonation in salt marshes is unclear. For example, some studies indicate that elevation may be the cause for plant zonation (Marshberger 1911, Johnson and York 1915, Reed 1947, Hinde 1954). However, Eleuterius and Eleuterius (1979) indicated that other factors, such as soil water salinity, may be involved, which are superimposed on the elevation-tide level relationship. Jackson (1952), Kurz and Wagner (1957), Adams (1963), and Shiflet (1963) indicated that soil water salinity was the primary factor affecting plant zonation in tidal marshes. Furthermore, Gillham (1957), Beestink (1966), and Ranwell (1972), have observed inversions of zonation to tidal submergence. These reports and the present study, where no differences in soil water salinity are found among populations, indicate that perplexing relationships exist among plant zonation, elevation, and tidal submergence. Palmisano (1970) and Palmisano and Chabreck (1972) have reported on the relationship between the soils and plant communities in Louisiana marshlands and no consistent relationships between soil nutrients and vegetational type were found. Considerable overlaps were observed in nutrient concentrations among vegetational types. Lanning and Eleuterius (1978) showed that the silica content of soils from four populations of *J. roemerianus* was different.

The Graveline Bay marsh plant populations studied are predominantly pure stands of the salt marsh species. The *S. olneyi* stand is a pure stand; however, occasional plants of *D. spicata* are found intermixed with *J. roemerianus*. A few plants of *Borrichia frutescens* are found around the edge of the *D. spicata* stand. The *S. alterniflora* stand contains an occasional plant of *Spartina cynosuroides*. The *S. patens* stand is pure. The fluctuations in the aerial plant mass during the seasons are considered to be typical of the respective salt marsh plant species. In late summer, *D. spicata* reaches maximum aerial mass; *J. roemerianus*, *S. patens*, and *S. olneyi* each reach maximum aerial mass in

spring; and *S. alterniflora* has the greatest aerial mass in autumn.

Results presented here show little variation in the elevation among plant populations in Graveline Bay marsh; however, *D. spicata* occurs at the highest elevation and *S. patens* occurs at the lowest elevation, with *J. roemerianus*, *S. alterniflora*, and *S. olneyi* occurring at approximately the same elevation. These data indicate that there are elevational differences among the five plant populations, but all of the populations only span an average range of 4.6 cm.

Soil water content values are consistently lower in the *D. spicata* population, when compared seasonally to the other plant populations. Soil water content values for the other plant populations seem to be similar to one another, although variations occur among seasons and populations. Soil water content and organic matter appear to be related to marsh elevation. The lowest water content and lowest amount of organic matter are found in the *D. spicata* population, which occurs at the highest elevation.

The seasonal soil water salinity values show only slight variations of less than 6 ppt among the plant populations. However, the soil water salinities are generally lower in winter and higher in summer. Although the soil water salinity values vary, there are no appreciable differences among the five plant populations. Orthophosphate and ammonia nitrogen concentrations from the soil water show seasonal variations for each plant population and also show a wide range of differences among plant populations for individual seasons.

Although the soil pH values found in the plant populations range from 3.7 to 7.7, they are typical for tidal marsh soils and correspond closely to those reported by Chabreck (1972). The percent of soil organic matter varied widely among the plant populations studied. Boyd (1970) showed that there was a correlation between soil organic matter content and soil nitrogen for aquatic plant habitats. This relationship was also found in the present study, where lower organic matter content in the soil corresponds to lower soil nitrogen concentration. The *D. spicata* population has the lowest mean amount of organic matter in the soil and the populations of *S. patens* and *S. alterniflora* have the greatest mean organic matter values. The mean total nitrogen concentration in the soil is considerably less in the *D. spicata* population than in other plant populations studied. Although the soil organic matter varied among the populations of *J. roemerianus*, *S. alterniflora*, *S. patens*, and *S. olneyi*, they all have similar soil total nitrogen concentrations.

Brubacher et al. (1973) reported large variations in phosphorus from the marsh soils of Louisiana. In the present study, soil phosphorus concentrations represent a wide range of values among the plant populations, but these concentrations are within the ranges of those reported by Brubacher et al. (1973). The *D. spicata* population has the greatest soil phosphorus concentration and *S. alterniflora*,

*S. patens*, and *S. olneyi* populations are considerably less. DeLaune and Patrick (1980) stated that nitrogen was more important than phosphorus to plant growth in Louisiana marshes.

Brupbacher et al. (1973) reported large variations in Ca and Mg for the marsh soils in Louisiana, however, our results show only slight variations. Dunstan and Windom (1975) have reported zinc concentrations in marsh sediments on the Atlantic Coast ranging from 14.9 to 69.6 ppm. We found the greatest mean concentrations of Mg in the *J. roemerianus* population and the lowest mean concentrations in the population of *D. spicata*. For the element Ca, the *D. spicata* population has the greatest mean concentrations and the *S. alterniflora* population the lowest. In the present study, soil concentrations of the element Zn show only a small range from a mean high of 7.73 ppm in the *S. patens* population to a low of 5.19 ppm in the *D. spicata* population.

Boyd and Hess (1969) showed that an increase in soil nutrients increased shoot production of *Typha latifolia*. The five plant species reported upon in the present paper

are represented by different standing crops. Biomass depends largely on the peculiar vegetative morphology of each species. Although our results reflect some differences in physical and chemical soil characteristics among the five salt marsh plant populations, their role in the sharp delineation between plant zones remains unknown. It should also be pointed out that the vegetational composition of the area studied here is not characteristic of all marshes in Mississippi. The Graveline Bay marsh is unusual in having five different kinds of plant populations present adjacent to one another. However, the study clearly shows that the five plant species can and do form populations on intertidal areas with similar soil characteristics and that they are capable of occupying the same terrain in some locations.

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Notes on Barnacles (Cirripedia: Thoracica) from the Gulf of Mexico

Stephen R. Gittings  
*Texas A&M University*

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## NOTES ON BARNACLES (CIRRIPEDIA: THORACICA) FROM THE GULF OF MEXICO

STEPHEN R. GITTINGS

Department of Oceanography, Texas A&M University

College Station, Texas 77843

**ABSTRACT** Examination of several collections of barnacles from the northern and western Gulf of Mexico made over the last 30 years has improved our knowledge of the distributions of several taxa previously considered to be absent or rare in those regions. *Conchoderma auritum* (Linnaeus) and *Heteralepas* sp. aff. *cornuta* (Darwin) are recorded for the first time from the Gulf of Mexico. *Conchoderma auritum*, *Conchoderma virginatum* (Spengler), *Heteralepas cornuta* (Darwin), *Balanus trigonus* (Darwin), *Balanus venustus* Darwin, and *Balanus amphitrite amphitrite* Darwin have broad distributions outside the Gulf of Mexico. *Tetraclita stalactifera stalactifera* (Lamarck) is abundant in the intertidal zones of the southwestern Gulf, but rare elsewhere in the Gulf of Mexico outside the Florida Keys. Spatial segregation of *Octolasmis hoeki* (Stebbing) and *Octolasmis lowei* (Darwin) on a host crab is discussed.

### INTRODUCTION

The purpose of this paper is to present information on the distribution of nine barnacle species in the Gulf of Mexico, based on an examination of the barnacles from regional museum collections. Two new records of barnacles for the Gulf of Mexico are presented: the lepadomorphs, *Conchoderma auritum* (Linnaeus), a pedunculate barnacle often attached to whales, and *Heteralepas* sp. aff. *cornuta* (Darwin). *Heteralepas cornuta* has been found attached to the stems of gorgonians and to other organisms below 90 m depth (Weisbord 1979). Species not previously known from the western Gulf of Mexico include *Conchoderma virginatum* (Spengler), a widely distributed, pelagic lepadomorph attached to various organisms and floating objects, *Tetraclita stalactifera stalactifera* (Lamarck), an intertidal balanomorph (often called "acorn" barnacles), and *Balanus trigonus* (Darwin), a subtidal balanomorph with a wide distribution. A review of the literature suggests that two intertidal and subtidal balanids documented herein from the northwestern Gulf, *Balanus amphitrite amphitrite* Darwin and *Balanus venustus* Darwin, may have been long overlooked or misidentified in the past. Finally, an examination of specimens of two crab-dwelling barnacles, *Octolasmis hoeki* (Stebbing) and *Octolasmis lowei* (Darwin), on *Calappa sulcata* Rathbun (Brachyura: Oxystomatidae) indicates the two species are spatially segregated on the body of this host.

The Gulf of Mexico is a semi-enclosed oceanic basin extending from approximately 18°N to 30°N and 81°W to 97°W on the western side of the Atlantic Ocean. Water enters the Gulf through the Yucatan Channel (176 km wide) and exits through the Florida Straits (144 km wide). The Loop Current, which directs this flow, is restricted to the eastern Gulf. The northward extent of the Loop Current varies considerably, typically ranging further north during the summer (Ichiye et al. 1973; Figure 1).

There are several important differences that distinguish

the western Gulf of Mexico from the eastern Gulf. First, with respect to circulation, the tropical waters of the Loop Current influence the western Gulf of Mexico much less than they do the Gulf east of the Mississippi River delta. Second, though the continental shelves off Florida and the Yucatan peninsula consist of carbonate sediments, the shelf in the northwestern Gulf consists of terrigenous sediments, which results in much higher turbidity (Rezak et al. 1983; Figure 1). Third, the influence of winter cold fronts on nearshore surface water temperature is most pronounced in the northwestern portion of the Gulf of Mexico (Rezak et al. 1983). Nearshore surface temperatures off Louisiana may be as low as 6°C for short periods in winter. Fourth, salinity in these same waters is strongly influenced by variability in the Mississippi/Atchafalaya discharge system and other rivers draining into the northwestern Gulf (Rezak et al. 1983). Most of the Mississippi River discharge flows west along the coast of Louisiana (Figure 1). Thus, the hydrography of the western Gulf of Mexico is very different from that of the eastern Gulf, especially in the northwestern region, where terrigenous sediments and highly variable salinity and temperature regimes predominate. Of the nine species discussed herein, *Tetraclita stalactifera stalactifera*, *Balanus trigonus* and *B. a. amphitrite* show regional differences in distribution and abundance that appear to be related to the above parameters.

Few barnacle collections made in the western Gulf of Mexico had been analyzed until recently. This was, in part, due to the lack of cirriped specialists in the region. Additionally, the lack of natural hard substrates has limited the number of cirriped collections in the northwestern Gulf of Mexico. It has been only in the last several decades that man-made hard substrates (e.g., jetties, oil rigs) have allowed the development of any substantial intertidal and subtidal fouling communities. Comparisons of present day biofouling community species composition with that from two to three decades ago suggest the region is still undergoing successional changes (Gunter and Geyer 1955, George and Thomas 1979).

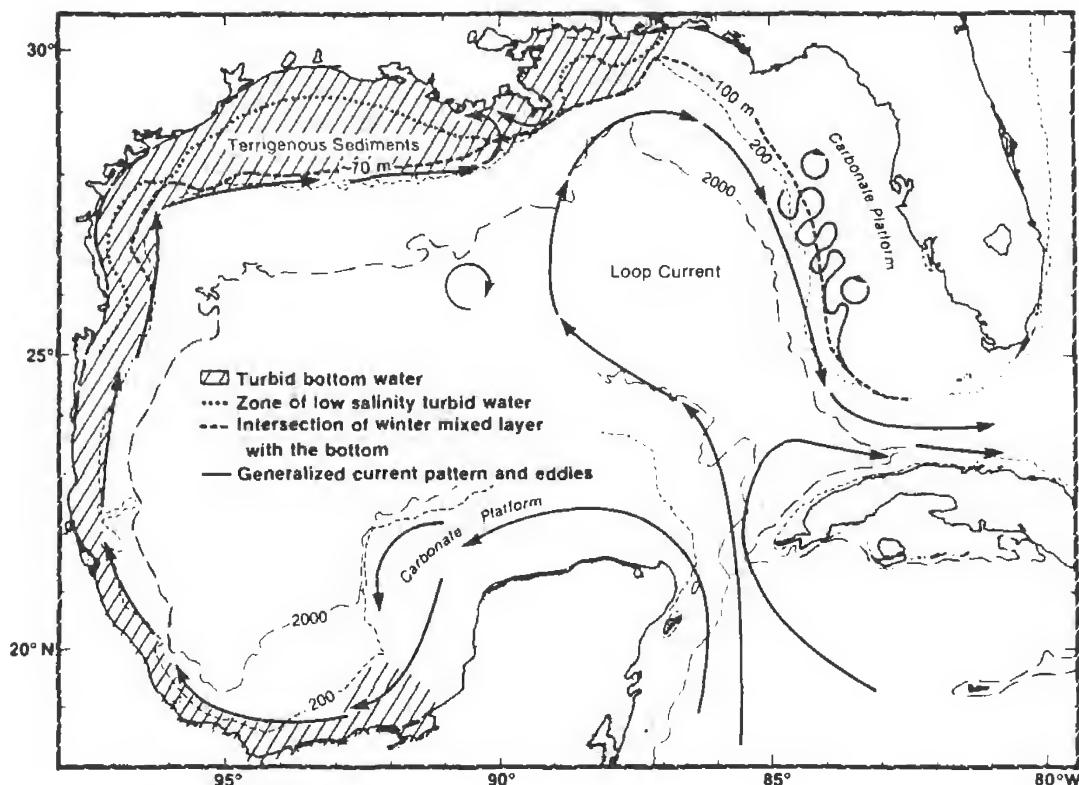


Figure 1. Map of the Gulf of Mexico summarizing circulation patterns, continental shelf bottom types, and turbid water regions. Arrows representing Loop Current show range of variability in flow pattern. Nearshore circulation patterns are not illustrated. Spin-off eddies represent mechanisms for dispersal of tropical organisms to continental shelf regions in both the eastern and western Gulf of Mexico. (Modified, with permission, from Rezak et al. 1983).

Most other collections from the western Gulf of Mexico included either deep-sea species or those epizoic on organisms collected for other studies. These collections include primarily trawl samples made by the M/V OREGON (1961–1968), the R/V OREGON II (1967–1977), the R/V ALAMINOS (1963–1973), and the R/V GYRE (1974 to present).

Spivey (1981) summarized the available information on the zoogeography of the Cirripedia of the Gulf of Mexico and provided a list of species occurring in the region. Based in part on the relatively low endemism of cirripeds (14%) and other invertebrate groups, and the wide overlap of temperate and tropical species, he determined that the Gulf of Mexico is a transition zone between tropical and warm temperate shelf faunas.

Abbreviations for collections reported herein are as follows: CCSU - personal collection of Dr. J. W. Tunnell, College of Science and Technology, Corpus Christi State University, 6300 Ocean Drive, Corpus Christi, Texas 78412;

GCRL - Gulf Coast Research Laboratory, Ocean Springs, Mississippi 39564; TAMU - Texas A&M University Systematics Collection, Dept. of Oceanography, College Station, Texas 77843; TAIU - Texas A&I University, Biology Dept., Kingsville, Texas 78363; UTMSI - University of Texas Marine Science Institute, Port Aransas, Texas 78373.

#### SYSTEMATICS

##### Order THORACICA Darwin, 1854

##### Suborder LEPADOMORPHA Pilsbry, 1916

##### Family LEPADIDAE Darwin, 1851

*Conchoderma auritum* (Linnaeus, 1767)

*Gulf of Mexico* — GCRL77:1075: from plastic band on head of dusky shark, *Carcharhinus obscurus* (Lesueur); about 16 km south of Pensacola, Florida; 21 July 1977; coll. T. Mattis; det. W. A. Newman.

**Remarks** — This record represents the only account of this species in the Gulf of Mexico. This occurrence was first presented, without collection data, by Overstreet (1978). Zullo (1979) considered *C. auritum* to be a cosmopolitan species, often found attached to whale barnacles and, occasionally, to ships. This species has also been found attached to the teeth, baleen, palate, and penis of whales (Dr. H. R. Spivey, Florida State University at Tallahassee, pers. comm.). The nearest record to the Gulf of Mexico is from Cape Hatteras, North Carolina, on an iron buoy (Weisbord 1979).

*Conchoderma virgatum* (Spengler, 1790)

**Northwest Gulf of Mexico** — Attached to gray triggerfish, *Balistes capricornis* Gmelin, found in sediment trap; south of Mobil oil platform (lease block HI-389), near East Flower Garden Bank, 27°54'N, 93°36'W; 5 February 1983; coll. L. S. Baggett.

**Remarks** — Published records (Wells 1966, Pequegnat and Pequegnat 1968, Dawson 1969) and unpublished records (GCRL68:811, GCRL72:1055) suggest that this species is common in the eastern Gulf of Mexico on floating objects and various marine organisms (also see Spivey 1981). *Conchoderma virgatum* is a cosmopolitan species found attached to ships, buoys, fish, parasitic copepods, etc. (Zullo 1979). Its occurrence off the northwestern Gulf coast, therefore, is not surprising.

Family HETERALEPADIDAE Nilsson-Cantell, 1921

*Heteralepas* sp. aff. *cornuta* (Darwin, 1851)

(Figure 2a)

**Gulf of Mexico** — GCRL67:750: 20 specimens on antipatharian; 29°15'N, 88°11'30"W, Offshore project Station 6; 92 m; 15 March 1967; coll. R/V GULF RESEARCHER.

**Remarks** — Dr. Victor Zullo (University of North Carolina at Wilmington, pers. comm.) found *H. cornuta* in the mid-1960's to be abundant on settling plates (several hundred individuals) from off Fort Lauderdale, Florida. Elsewhere in waters adjacent to the Gulf of Mexico, the species is known from off Cape Lookout, North Carolina (91 m depth, Ross 1964). It has also been found at several locations in the eastern Atlantic (Weisbord 1979), in the Indian Ocean (Nilsson-Cantell 1938), and at one location in the eastern Pacific (Ross 1975). Ross (1975), however, suggested that those reported from the Indian Ocean may be referable to *H. japonica* (Aurivillius), a closely related species. Collection depths range from 90 m to 4315 m. The above record represents the only report of this genus and species from the Gulf.

The specimens examined differ somewhat from *H. cornuta*, described originally by Darwin (1851) from St. Vincents, West Indies, and from those examined by Ross (1975) from the eastern Pacific, in the number of segments comprising the rami of the 5th and 6th cirri and

the caudal appendages. The posterior (rudimentary) rami of the Gulf of Mexico specimens have between 8 and 11 segments and the anterior rami have 42–46 segments. Caudal appendages contain 6 segments. For this species, Darwin indicated between 11 and 13 segments for the posterior rami, although a ramus of 8 segments is illustrated (his Plate X, Figure 28), 63 segments for the anterior rami of the 6th cirri and 8 for the caudal appendages. Ross (1975) indicated 12 to 15 segments for the posterior rami, 52 to 53 segments for the anterior rami, and 9 segments for the caudal appendages. Without comparisons to other material, I chose not to assign the present specimens to *H. cornuta*. It is, however, likely that segment number varies in *H. cornuta*, based on comparisons of descriptions by Darwin (1851), Broch (1927) and Ross (1975). Segment number is known to vary considerably in a closely related and better known species, *H. japonica* (Aurivillius 1894, Foster 1978).

Family POECILASMATIDAE Nilsson-Cantell, 1921

*Octolasmis hoeki* (Stebbing, 1895)

(Figure 2b)

*Octolasmis lowei* (Darwin, 1851)

(Figure 2c)

*Synonymy of local occurrence for Octolasmis lowei:*

*Octolasmis mulleri* (Coker): Pilsbry 1907, pp. 95–96, fig. 32c; Pearse 1952, p. 238; Hulings 1961, p. 216.

**Western Gulf of Mexico** — *O. hoeki*: TAMU-2-6487: 12 on epipods of 3rd maxillipeds of *Calappa sulcata* Rathbun; 28°19'N, 95°23.8'W; 38 m; 4 June 1971; coll. R. M. Darnell.

— *O. hoeki*: TAMU-2-6489: 19 on epipods of 3rd maxillipeds of *Calappa sulcata*, with *Octolasmis lowei*; 23°58.4'N, 97°29.5'W; 37 m; 24 September 1971; coll. R. M. Darnell.

— *O. lowei*: TAMU-2-6488: 23 inside gill chamber of *Calappa sulcata*; 28°40.7'N, 94°47.7'W; 22–27 m, 7 July 1972; coll. W. E. Pequegnat.

— *O. lowei*: TAMU-2-6490: inside gill chamber of *Calappa sulcata*, with *Octolasmis hoeki*; 23°58.4'N, 97°29.5'W; 37 m; 24 September 1971; coll. R. M. Darnell.

**Remarks** — *Octolasmis lowei* is known to occur in the gill chambers of several crab species (Pilsbry 1907, Pearse 1952, Wells 1966, Jeffries et al. 1984) and is considered to be a cosmopolitan species (Causey 1961). It has not, however, been reported from the eastern Pacific (Weisbord 1979). *Octolasmis hoeki*, a tropical to north temperate Atlantic species (Spivey 1981), has been found "on the subbranchial region of *Calappa flammea*" (Hulings 1961) and on the mouthparts of palinurids (Stebbing 1895, Gravel 1905). Wells (1966) incorrectly paraphrased Hulings (1961), saying *O. hoeki* was found "in" the branchial chamber of *C. flammea*. Co-occurrence of these species on the same host has been noted by Causey (1961). I have found both species on several large specimens of *C. sulcata* from the

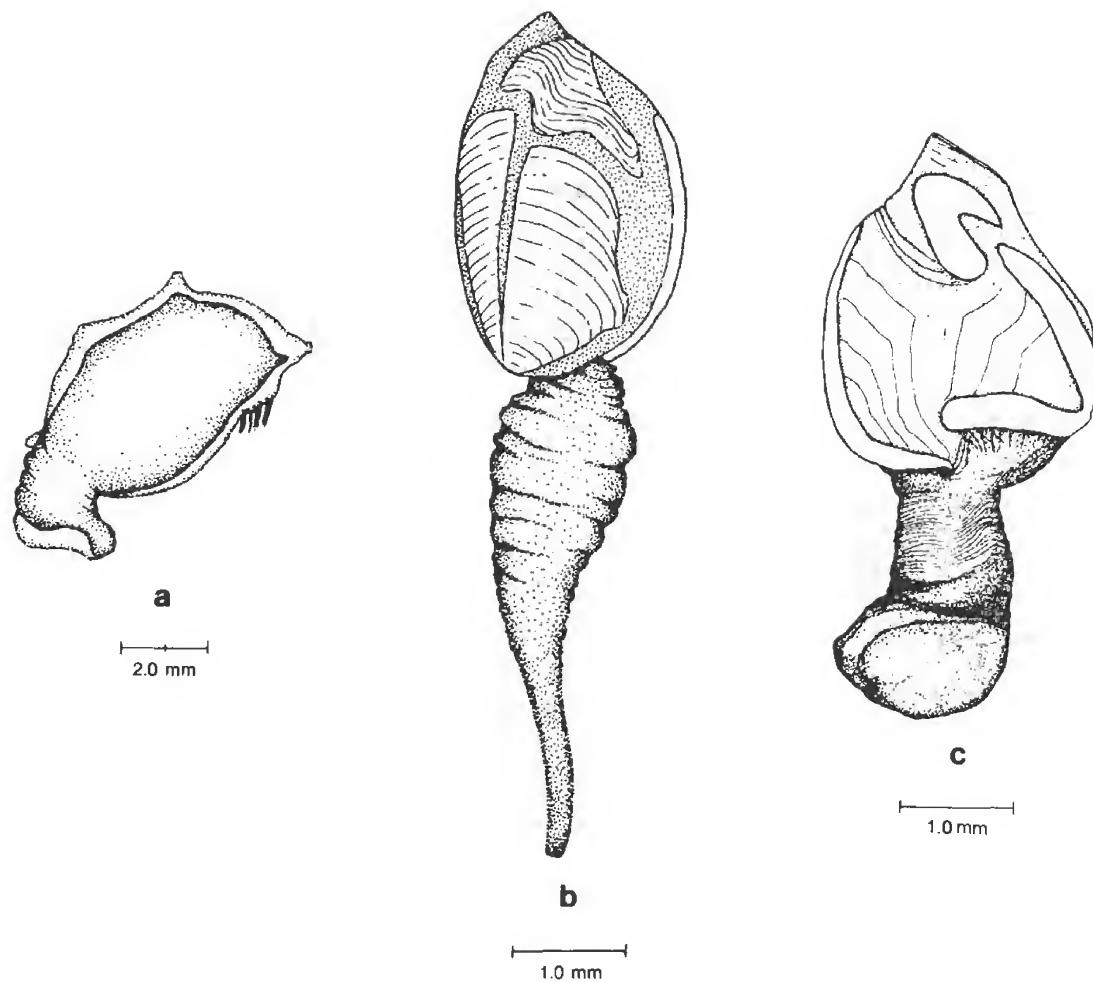


Figure 2. Lateral views of: (a) *Heteralepas* sp. aff. *cornuta* (Darwin); (b) *Octolasmis hoeki* (Stebbing); (c) *Octolasmis lowei* (Darwin).

western Gulf of Mexico. Data from one crab are given above (TAMU-2-6489 and TAMU-2-6490). Never were both species found to occur together on the same body region of a crab. There is a clear spatial segregation between *O. lowei* within the branchial chambers of *C. sulcata* (on the gills and in the gill chambers) and *O. hoeki* outside the chambers (on the mouthparts, the carapace near the gills, and on the exoskeleton of the first walking legs near the branchial chamber). These spatial preferences are evident even in cases where only one species is present.

**Suborder BALANOMORPHA Pilsbry, 1916**

**Family TETRACLITIDAE Gruvel, 1903**

***Tetraclita stalactifera stalactifera* (Lamarck, 1818)**

**Synonymy of local occurrence:**

*Tetraclita squamosa stalactifera* Lamarck: Stephenson and Stephenson 1950, p. 388; Henry, 1954, p. 444.

*Western Gulf of Mexico* – UTMSI: 1 individual from jetty, Tuxpan, Mexico, 21°00'N, 97°15'W; intertidal, with *Chthamalus fragilis* Darwin; 24 December 1954; coll. H. H. Hildebrand.

– UTMSI: from Boca Andrea, Veracruz, Mexico, 19°15'N, 96°08'W; no date; coll. H. H. Hildebrand.

– CCSU: 6 individuals; Isla de Lobos, Mexico, 21°27'N, 97°15'W; station I-7-4; 7 June 1973; coll. J. W. Tunnell.

– CCSU: 1 individual; Isla de Lobos, Mexico, 21°27'N, 97°15'W; windward reef, south side, *Acropora* zone, 1.5 to 4.5 m; station 76-14-1; 14 June 1976; coll. J. W. Tunnell.

– CCSU: 13 individuals; Isla de Lobos, 21°27'N, 97°15'W; *Acropora* zone, west of boulder ridge on leeward

side of island, 1 to 3 m; station 76-14-2; 14 June 1976; coll. J. W. Tunnell.

— TAMU, uncataloged: 4 individuals, the largest 3.5 cm carino-rostral length, with *Balanus reticulatus* Utinomi and *Megabalanus antillensis* (Pilsbry); Mobil oil platform (lease block HI-389), 2 km southeast of East Flower Garden Bank, 27°54'N, 93°36'W; near surface; 26 March 1984, R/V GYRE cruise 84-G-3; coll. G. D. Dennis.

**Remarks** — *Tetraclitia stalactifera stalactifera* is found intertidally in the western Atlantic from Florida to Brazil (Southward 1975). Newman and Ross (1976) also list the species from Bermuda, the Gulf of California south to Acapulco, Mexico, the Arabian Sea, and South Africa.

These are the only records of this species in the Gulf of Mexico outside the Florida Keys (see Stephenson and Stephenson 1950, Henry 1954), and the Yucatan peninsula (Spivey, pers. comm.), and support, in general, Southward's (1975) conclusion that the distribution of *T. s. stalactifera* is intertidal in relatively clear waters. This species has not been found on any natural or man-made structures in the turbid nearshore waters of the northern Gulf of Mexico. It is apparently common in Mexican waters north to at least Cabo Rojo. It is not known from north of Cabo Rojo in the Gulf, except from the oil platform near the East Flower Garden Bank, approximately 177 km SSE of Galveston, Texas. The water near this shelf-edge bank is very clear and temperatures are always above 18°C. In the southwestern Gulf, *T. s. stalactifera* has been found attached to both artificial and natural substrates, including the dead portions of storm-tossed *Acropora palmata* (Lamarck) branches and coral heads on the crests of coral reefs (Dr. J. W. Tunnell, Corpus Christi State University, pers. comm.).

#### Family BALANIDAE Leach, 1817

##### *Balanus trigonus* Darwin, 1854

**Northwest Gulf of Mexico** — TAMU, uncataloged: on plastic recruitment floats; 10 km south of Holly Beach, Louisiana; settled between June and August 1982 and September to October 1983 (Gittings 1984 and unpublished data, respectively), with *Balanus reticulatus*, *B. improvisus* Darwin and *B. eburneus* Gould; 8–10 m; coll. S. R. Gittings.

— UTMSI: 22 live, 9 dead, on *Busycon*, 17 live, 5 dead, on another *Busycon*, in trawl; Redfish Bay, near Port Aransas, Texas; 3 m; 22 April 1984; coll. R. D. Kalke.

— TAMU, uncataloged: on *Crassostrea virginica* (Gmelin), with *B. eburneus*; Aransas Bay, Texas, near causeway from Port Aransas to Aransas Pass; salinity 31 ppt; 27°C; 0.6 m; 21 September 1984; coll. S. R. Gittings.

— TAMU, uncataloged: abundant on seaward end of rock jetty, subtidal to 6 m depth, with *Megabalanus antillensis*, *Chthamalus fragilis*, and *Balanus amphitrite amphitrite*; also on gorgonians; Port Mansfield, Texas; 13 August 1984; coll. S. R. Gittings.

— TAMU, uncataloged: on bay scallop, *Argopecten irradians* (Lamarck); Laguna Madre, Texas, near spoil island

just south of Mansfield Channel; 0.5 m; 13 August 1984; coll. S. R. Gittings.

— TAMU, uncataloged: on terra cotta recruitment plates and PVC support structure 1 m above live coral reef (Mr. L. S. Baggett, Texas A&M University, pers. comm.), settled 1982–1983; East Flower Garden Bank (27°54'N, 93°36'W); 21 m; coll. L. S. Baggett.

**Remarks** — It is surprising that *B. trigonus* has not been reported until now from the western Gulf of Mexico, since it is cosmopolitan in warm seas and its distribution, for the most part, is natural (i.e., unaltered by man's activities; Newman and Ross 1976). I have found it to be quite abundant and widespread in both turbid and clear waters off Texas and Louisiana, although it is seldom a principal fouler of stationary structures. Perhaps, as suggested by Wells (1966), *B. trigonus* has within the last several decades been extending its range. Hedgpeth (in Whitten et al. 1950) thought "*B. amphitrite niveus* . . . is probably the species seen covering rocks below the *Chthamalus fragilis* zone at the end of the [Port Aransas, Texas] jetty" (p. 76). The balanid material of Whitten et al., although not available for study, may be referable to *B. trigonus*, which I have seen occupying an identical position on the Port Mansfield (Texas) jetty.

The distribution of *B. trigonus* in Texas bays may be limited by high water temperatures during the summer. Ritz and Foster (1968) found that cirral activity for *B. trigonus* living in an area with a temperature range of 11–21°C increased to a temperature optimum of 27°C, with cessation of activity at 31°C. In Texas bays, summer water temperatures may exceed 32°C.

##### *Balanus amphitrite amphitrite* Darwin, 1854

**Northwest Gulf of Mexico** — CCSU: Corpus Christi Bay, Texas, north beach under harbor bridge; with *Balanus eburneus*; salinity 27 ppt; 16°C; 7 February 1980; coll. J. W. Tunnell.

— TAMU, uncataloged: 3 on Scotch Bonnet shell, *Phalium granulatum* (Born), with *Balanus eburneus*; Redfish Bay, Texas; <1 m depth; February 1984; coll. T. J. Bright.

— TAMU, uncataloged: 6 live, 30 dead, from public boat ramp; Port Mansfield, Texas, mainland side of Laguna Madre; intertidal; 24 February 1984; coll. T. J. Bright.

— UTMSI: abundant on samples of serpulid reef from Baffin Bay, Texas; approximately 1 m depth; no date.

— TAMU, uncataloged: 11 live, 5 dead, on oysters, *Crassostrea virginica*; Redfish Bay, Texas, oyster reef near causeway from Port Aransas to Aransas Pass, Texas; with *Balanus reticulatus* (dead) and *Balanus eburneus*; 23 March 1985; coll. M. K. Wicksten.

**Remarks** — *Balanus amphitrite amphitrite* has a cosmopolitan distribution in warm seas (Newman and Ross 1976). The occurrence of this species intertidally on pilings and rocks at Corpus Christi Bay Beach, Corpus Christi, Texas,

was noted in 1971 by Spivey (pers. comm.). Wells (1966) and Henry and McLaughlin (1975) reported its presence to the east, off Panama City, Florida, and to the south, off Veracruz, Mexico, but cited no localities in the northwest Gulf of Mexico. Though Hedgpeth (in Whitten et al. 1950) reported *B. a. niveus* from the Port Aransas, Texas, jetties, and Gunter and Geyer (1955) reported *B. amphitrite* from platforms off Texas and Louisiana, it is not clear whether their specimens were *B. a. amphitrite*, *B. reticulatus*, *B. venustus* (with which *B. a. niveus* was later synonymized; Harding 1962), or, perhaps, even *B. trigonus*, as discussed previously.

Thomas (1975) suggested that *B. a. niveus* reported by Whitten et al. (1950) was *B. venustus*. Though *B. venustus* occurs in the western Gulf of Mexico, it is not common, and it is doubtful that it occurs at any time on jetties in abundances seen by Whitten et al. (1950). *Balanus trigonus* is the only species I have seen to occur in abundances reported by Whitten et al. (1950) on the ends of (south) Texas coast jetties.

Analysis of recent collections suggests that *B. a. amphitrite* is a common species, though not in high abundance, on man-made structures in shallow south Texas bays. It is less frequently observed in the more northern bays. Personal collections have not confirmed *B. a. amphitrite* on any offshore oil structures or artificial settling substrates in the northwestern Gulf of Mexico. These are occupied predominantly by *B. reticulatus* nearshore in the northern Gulf (Thomas 1975) and by *Megabalanus antillensis*, *B. trigonus*, and *B. reticulatus* on offshore and south Texas structures.

#### *Balanus venustus* Darwin, 1854

*Northwest Gulf of Mexico* — TAIU: approximately 24 on shell dredged from 7½ Fathom Reef, 26°51'N, 97°18'W, north of Port Mansfield, Texas; 27 July 1973.

— TAMU, uncataloged: about 25 on moon snail, *Polinices duplicatus* (Say); in Laguna Madre, Texas, near Mansfield Channel marker 15, 26°33.5'N, 97°20'W; salinity 42 ppt; 29.5°C; 13 August 1984; coll. S. R. Gittings.

— TAMU, uncataloged: numerous, on oysters attached to dead gorgonian (*Leptogorgia*?); north side of north jetty at Mansfield cut, Texas; salinity 35 ppt; 29.5°C; 13 August

1984; coll. T. J. Bright.

**Remarks** — Henry and McLaughlin (1975) documented *B. venustus* from Heald Bank, off Texas (approximately 29°04'N, 94°17'W), the only published record of the species west of Panama City, Florida, and north of Campeche Bay, Mexico. This species is represented in a collection returned by the R/V ALAMINOS from 22 m at location 28°41'N, 94°48'W, according to Spivey (pers. comm.).

*Balanus venustus* occurs in the eastern Atlantic, the tropical to north temperate western Atlantic, and the Indo-Pacific (Spivey 1981). It occurs in highest abundances on mollusc shells rather than on artificial surfaces. A notable exception was that reported by Pequegnat and Pequegnat (1968), who found it to occur in abundance on plastic fouling recruitment floats off Panama City, Florida. Aside from the report by Hedgpeth (in Whitten et al. 1950) of *B. amphitrite niveus* seen (but not examined) on the Port Aransas (Texas) jetties (discussed earlier in the sections on *B. trigonus* and *B. a. amphitrite*), no unquestioned reports exist for *B. venustus* on artificial substrates in the northwestern Gulf of Mexico.

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My thanks go to the curators of the regional museum collections for their kindness and assistance during my visits, Mr. Charles Dawson, Gulf Coast Research Laboratory, Mr. Rick Kalke, University of Texas Marine Science Institute, and Dr. Allan H. Chaney, Texas A&M University. Thanks also to Dr. J. W. Tunnell for making his collection available to me. The generous efforts of Mr. George Dennis, who assisted me in sampling and in examining museum specimens, and those of Bonnie Bower-Dennis and Bryan L. Andryszak, who prepared the specimen figures, are appreciated. Thanks also to Dr. Henry Spivey, Dr. Mary K. Wicksten, Dr. R. Hays Cummins, Mr. George Dennis, and Mr. Jim Parrack for reviewing the manuscript. This research was partially supported by funds from the Department of Energy Strategic Petroleum Reserve Program, contract number DE-AC96-80PO10288 to Texas A&M University, and by a grant from the Texas A&M University Oceanography Departmental Development Fund.

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# Gulf Research Reports

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## Spatial Influences on Temporal Variations in Leaf Growth and Chemical Composition of *Thalassia testudinum* Banks Ex König in Tampa Bay, Florida

Michael J. Durako

*Florida Department of Natural Resources*

Mark D. Moffler

*Florida Department of Natural Resources*

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## SPATIAL INFLUENCES ON TEMPORAL VARIATIONS IN LEAF GROWTH AND CHEMICAL COMPOSITION OF *THALASSIA TESTUDINUM* BANKS EX KÖNIG IN TAMPA BAY, FLORIDA

MICHAEL J. DURAKO AND MARK D. MOFFLER

Florida Department of Natural Resources, Bureau of Marine Research,  
100 Eighth Avenue S.E., St. Petersburg, Florida 33701

**ABSTRACT** The importance of spatial influences on seasonal fluctuations in *Thalassia testudinum* leaf blade lengths and chemical constituents was demonstrated. Differences between samples from fringe and mid-bed for several constituents were significant and, if not accounted for, could affect the measurement of apparent seasonal cycles. Fringe-shoots, reflecting the influence of more intense grazing activity, had shorter leaf blade lengths, lower dry weights and carbohydrate levels, and higher protein levels than mid-bed shoots. Mid-bed rhizomes and roots had highest protein and ash levels reflecting possible sediment influence. Percent ash and protein in the rhizomes, and percent carbohydrate in the roots exhibited seasonal fluctuations, but the levels were different between fringe and mid-bed samples. Protein levels were greatest in shoots and roots, while carbohydrate levels were highest in rhizomes, illustrating the respective partitioning of biosynthetic and storage functions. The spatial differences seem to reflect gradients in biological and chemical interactions, and they may play an important role in trophic interactions in seagrass systems.

### INTRODUCTION

Studies on chemical composition of several seagrass species have demonstrated the presence of annual cycles (Walsh and Grow 1972, Harrison and Mann 1975, Dawes et al. 1979, Dawes and Lawrence 1980). Walsh and Grow (1972) and Dawes and Lawrence (1980) showed that in the dominant Florida seagrass, *Thalassia testudinum*, protein levels generally were highest in spring and early summer, while carbohydrate, ash, and dry weight levels peaked in the fall. Rhizomes contained relatively large amounts of carbohydrates, and function as storage organs for nutrient reserves. In contrast, leaves and shoots usually had higher protein levels than rhizomes due to greater biosynthetic activity.

Most previous studies of seasonality in seagrasses have utilized random sampling techniques which assumed that seagrass meadows were uniform communities. However, when environmental or successional gradients are suspected in a plant community, sampling along transects is more appropriate than random sampling (Whittaker 1967). In this regard, Zieman (1972) reported lower leaf blade densities and shorter blade lengths at the fringe compared to the center of circular beds of *T. testudinum* in Biscayne Bay, Florida. Capone and Taylor (1977), also working in Biscayne Bay, found that the dry weight of leaves per short-shoot and the number of leaves per square meter were lower at the fringe of a *T. testudinum* bed than in the interior. They also reported higher N<sub>2</sub> fixation activity associated with intact foliage at the fringe. Additional spatial trends have been observed in temperate *Zostera marina* L. meadows (Fonseca 1981, Kenworthy 1981). Kenworthy (1981) noted the largest pools of sedimentary

nitrogen, finest sediments, and highest shoot production may be associated with the mid-bed regions of *Z. marina* meadows. He suggested that fringe areas represent colonizing stages of growth, while mid-bed regions illustrate later successional stages. Organic matter content of sediments and leaf area index (LAI) may also increase with distance into a bed (Fonseca 1981).

This study examined the spatial and temporal variations of chemical constituents in *T. testudinum* shoots, rhizomes, and roots. We utilized transect sampling to determine: (1) the allocation of chemical constituents within plant organs, (2) if spatial variations between the fringe and the interior of a seagrass bed differed significantly, and (3) if the spatial differences were large enough to obscure apparent seasonal patterns.

### MATERIALS AND METHODS

Samples of *T. testudinum* were obtained monthly from a small circular seagrass bed (approx. 23 m dia) adjacent to Lassing Park (27°45'N, 82°38'W) in Tampa Bay, Florida (see description of Beach Drive, SE, Phillips 1960). Samples were obtained using a posthole digger (approx. 15 cm dia by 20 cm deep). Eleven sample plugs were removed each month at alternate meters along transects which bisected the bed and extended from fringe to fringe. January's transect was oriented along the east-west axis of the bed. Subsequent transects were rotated 30 degrees so the bed was ultimately bisected by six transects which were sampled twice over the 12-month study period. Samples one and eleven represented the fringe of the bed while samples four through eight were considered the mid-bed region. Water depth and the length of the longest intact leaf blade from four randomly chosen shoots (short-shoots) were measured at each sample point. Water temperature and salinity were measured each month.

Plugs were washed free of sediment and separated into shoot, rhizome, and root fractions within 2 h of collection. Floral and faunal epiphytes were removed from the leaf blades by gently scraping under a stream of water. Each fraction was then blotted dry and weighed (fresh weight), dried at 60°C to constant mass, and reweighed to determine percent dry weight. The entire dried fractions were ground in a mill (screen size #40) and stored in a dessicator over  $\text{CaCl}_2$  until the chemical analyses were performed.

Percent ash was determined by weight loss after combustion of duplicate 50-mg subsamples in a muffle furnace at 500°C for 4 h. Protein was measured after extraction of 30-mg subsamples with 1 N NaOH by Folin reagent using bovine serum albumin as the standard (Lowry et al. 1951). Soluble carbohydrate was measured after extraction of 10-mg subsamples with 5% hot trichloroacetic acid (TCA) by the phenol-sulfuric acid method (Dubois et al. 1956) using glycogen as the standard. Protein and carbohydrate analyses were done in triplicate. The levels of the constituents were expressed as percentage of dry weight.

Seasonal patterns were statistically analyzed using data pooled from all samples of a transect, whereas spatial distinctions were determined by pooled monthly data for each sample point. Normality of the data was assessed using Kolmogorov-Smirnov tests for normality ( $p < 0.05$ ). Multivariate analyses of variance were performed to determine if chemical constituents exhibited significant ( $p < 0.05$ ) temporal or spatial variation. If significant variation occurred, means were compared using Duncan's multiple range tests ( $p < 0.05$ ). Calculations were performed using Statistical Analysis System (SAS) computer programs (Barr et al. 1976). The SAS/GCONTOUR procedure was used to generate a contour map of the circular bed utilizing water depth data.

## RESULTS

### *Seasonal variations*

Pronounced seasonal variations of salinity, water temperature, and leaf blade lengths were evident at Lassing Park. Although salinity fluctuated between 25 and 28 ppt for 75% of the year reaching highest levels during the early summer (Figure 1a), high rainfall amounts in late summer--early fall resulted in substantially reduced salinities. Water temperature (Figure 1b) and mean longest leaf blade lengths (Figure 2) exhibited similar seasonal patterns; they increased from spring to summer and decreased from fall to winter. Maximum leaf blade lengths decreased slightly during the summer (Figure 2), coincident with highest water temperatures, floral anthesis, and initial fruit development. Water temperatures ranged from 11.5°C to 31.5°C during the year, while leaf lengths varied from 13.4 cm to 23.3 cm.

Seasonal variability was also evident in the chemical composition of *T. testudinum* and the patterns were generally distinctive between plant organs (Table 1).

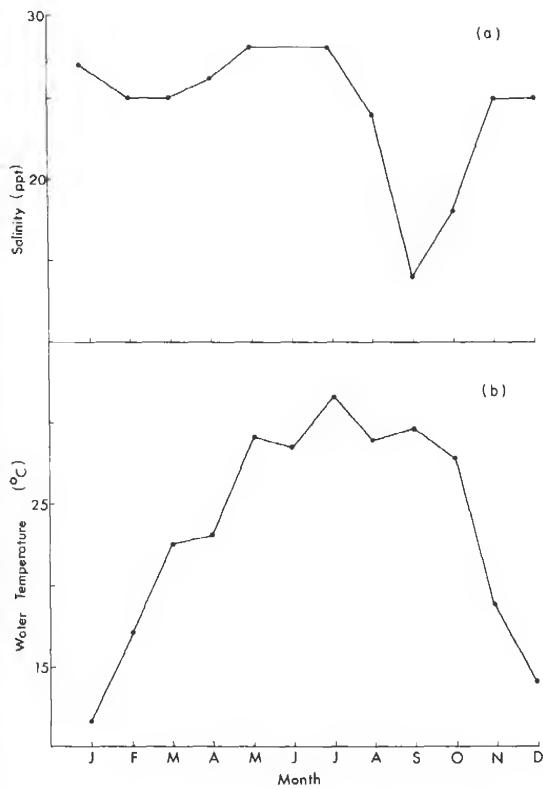


Figure 1. Seasonal fluctuations in (a) salinity and (b) water temperature at Lassing Park site.

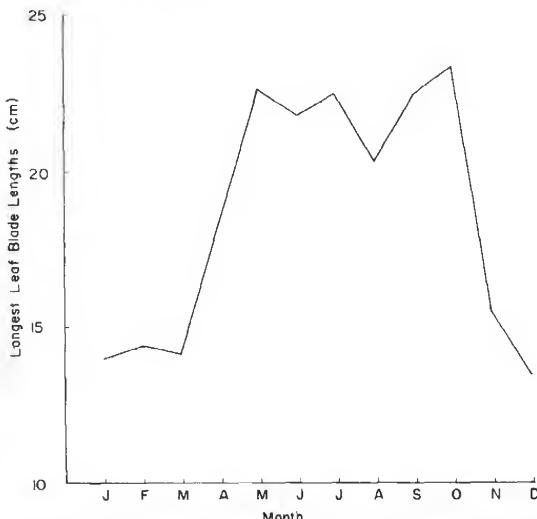


Figure 2. Seasonal fluctuations in maximum leaf blade lengths for *Thalassia testudinum* from Tampa Bay, Florida.

TABLE I

Seasonal proximate analyses of *Thalassia testudinum* from Tampa Bay, Florida. Dry weight is expressed as a percentage of fresh weight.  
 Ash, protein, and soluble carbohydrate levels are expressed as percentage of dry weight.  
 Means of pooled transect samples  $\pm$  one standard deviation are listed,  $n = 11$ .

Component	Months											
	Jan	Feb	Mar	Apr	May	Jun	Jly	Aug	Sep	Oct	Nov	Dec
<b>Shoots</b>												
Dry weight	11.88	10.63	10.46	10.55	9.64	10.44	10.28	10.49	10.28	10.49	9.97	9.99
$\pm$	1.15	0.99	0.94	1.02	0.61	0.81	0.69	0.40	0.78	0.86	0.72	0.84
Ash	42.7	24.6	25.1	28.5	34.0	34.5	30.2	25.9	25.7	26.1	27.0	28.2
$\pm$	7.3	5.3	4.4	2.6	4.1	3.8	2.5	2.9	1.4	2.2	3.6	5.6
Protein	4.0	2.8	3.3	3.4	2.4	3.3	3.0	4.2	5.1	4.0	3.6	3.2
$\pm$	1.3	1.1	0.9	1.0	0.7	1.3	1.1	1.0	2.4	1.4	0.8	1.0
Carbohydrate	9.9	16.1	14.5	11.8	11.9	13.5	10.8	13.8	14.3	16.1	14.5	13.3
$\pm$	2.5	6.6	2.9	1.7	1.7	2.4	1.4	4.0	3.1	3.7	3.6	3.8
<b>Rhizomes</b>												
Dry weight	15.78	16.30	16.36	15.98	15.15	16.03	16.89	16.85	16.74	15.84	15.87	16.14
$\pm$	3.21	0.78	0.91	0.87	1.62	1.33	0.96	1.37	2.04	0.83	0.86	0.68
Ash	26.7	21.6	22.7	23.7	23.9	23.4	21.4	19.5	20.5	19.4	21.4	21.5
$\pm$	5.1	1.2	1.7	2.1	1.4	2.4	1.3	2.0	2.1	1.4	1.5	1.2
Protein	2.8	1.7	1.2	1.3	1.3	1.5	1.2	1.2	2.4	1.5	1.3	1.0
$\pm$	1.0	0.6	0.4	0.7	0.4	0.9	0.7	0.3	0.9	0.4	0.3	0.3
Carbohydrate	19.4	24.7	23.2	23.7	22.8	21.6	26.5	31.8	30.8	30.4	28.1	27.5
$\pm$	4.4	5.3	5.1	1.9	4.6	5.9	6.2	8.6	6.5	6.6	4.5	4.3
<b>Roots</b>												
Dry weight	—	13.02	14.58	14.32	13.16	13.33	12.88	11.22	11.49	11.98	11.77	12.29
$\pm$	—	1.00	1.80	1.52	1.65	1.56	0.94	1.28	1.52	1.93	0.84	1.22
Ash	—	31.9	31.4	36.1	33.6	32.5	30.5	26.5	26.6	25.7	26.4	25.8
$\pm$	—	3.7	6.3	7.5	3.8	3.7	3.3	1.8	1.7	3.8	1.9	5.9
Protein	—	3.6	3.5	3.0	4.0	3.9	3.9	4.7	4.6	4.3	5.0	4.2
$\pm$	—	0.8	0.9	1.3	1.4	0.8	1.4	1.0	1.5	1.0	1.2	1.4
Carbohydrate	—	9.9	9.4	12.0	10.5	12.0	12.1	12.6	15.1	12.1	13.4	11.7
$\pm$	—	1.7	1.4	2.2	2.1	3.2	3.0	3.1	3.5	2.7	1.9	1.9

Dry weights of shoots were significantly greater in January than in any other month and lowest in May. The highest dry weights in rhizomes occurred in late summer–early fall and were also lowest in May. Root dry weights, highest during the spring, decreased significantly during the summer, reaching minimum values in the fall. Shoots had the lowest dry weights (9.5–11.8%) and rhizomes had the highest (15.1–16.9%); roots were intermediate (11.2–14.6%). Ash levels exhibited seasonal patterns that were similar in all three organs. Low ash levels were present during early spring and fall, while highest levels occurred during late spring–early summer with a peak in January. This pattern corresponded with fluctuations in salinity (compare Figure 1a and Table 1). Ash levels were highest in shoots (24–42%) and lowest in rhizomes (19–27%); roots were again intermediate (25–36%).

Carbohydrate levels in shoots exhibited a bimodal seasonal pattern with peaks in February and October (Table 1). The seasonal pattern exhibited by both rhizomes and roots was slightly different; levels were lowest during spring then increased significantly during the late summer–early fall. Carbohydrate levels in shoots and roots ranged from 9 to 16.5%; levels in rhizomes were significantly

higher (19–32%). Protein levels in shoots and rhizomes were lowest in spring and highest in January and September. Root levels were low in spring and increased through fall. Protein levels of shoots and roots (2–5%) were similar and always higher than those of rhizomes (1–3%).

#### *Spatial variations*

The seagrass bed we sampled had a “domelike” profile and water depth decreased approximately 10 cm from fringe to mid-bed, a lateral distance of about 10 m (Figure 3). Except for fringe samples, leaf lengths also tended to decrease toward the interior of the bed (Figure 4). The relatively short leaf blade lengths of fringe short-shoots, although in deeper water, were attributed to grazing activity which is more prevalent along fringe areas of these seagrass beds (personal observation).

Dry weight levels of shoots were significantly greater (10.5–10.9%) in the interior of the bed than on the fringe (Table 2). Roots exhibited the opposite trend and rhizomes showed no significant differences across the bed. Ash levels in shoots decreased significantly from the landward fringe (33.3%) to the seaward fringe (27.9%) (Table 2), while rhizomes had highest ash levels in the interior of the

bed (22.3–23.0%) and the lowest levels at the fringe (21.0 and 21.3%). Ash levels in roots fluctuated across the bed with little apparent pattern, but highest levels occurred in the mid-bed region.

Carbohydrate and protein levels in shoots and roots were

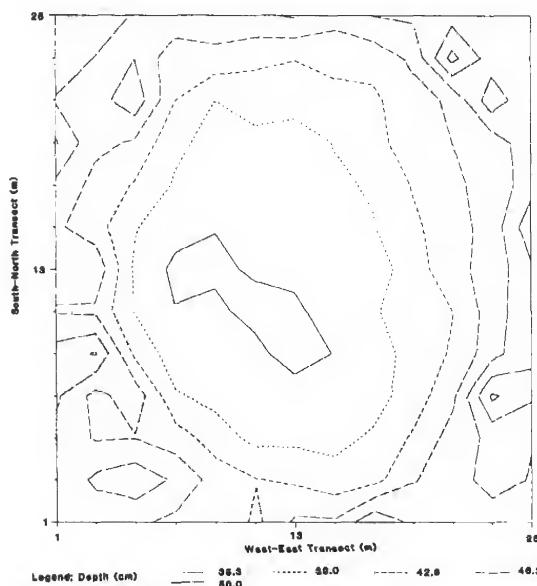


Figure 3. Depth profile of the circular *Thalassia testudinum* bed at Lassing Park showing mounded bed form.

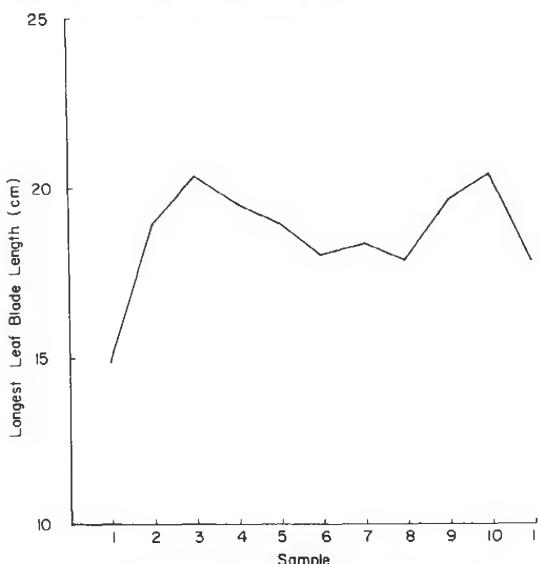


Figure 4. Spatial variation in maximum leaf blade length of *Thalassia testudinum* along transects through the circular bed.

inversely related along transects (Table 2). Carbohydrate levels of shoots were significantly lower at the fringe (10.9 and 12.6%) than in the interior (13.2–14.4%, except for sample #4). The opposite was true for protein levels. Root carbohydrate levels were significantly greater at the fringe while protein levels were significantly lower. Spatial variations in rhizome carbohydrate and protein were distinctive. The seaward fringe rhizomes had significantly more carbohydrate than the rest of the bed; but the interior had significantly higher protein levels.

Analyses of variance indicated samples obtained at the fringe of this *T. testudinum* bed had mean levels significantly different than those obtained from the interior for dry weight in shoots, percent ash and protein in the rhizomes, and percent carbohydrate and protein in roots. No significant synergistic interactions occurred between the month of sampling and sample location.

## DISCUSSION

### Seasonal variations

Seasonal patterns observed in this study, based on pooled transect data, agree closely with those previously reported for *T. testudinum* using random sampling techniques. Maximum leaf lengths of *T. testudinum* at Lassing Park exhibited a bimodal seasonal pattern with peaks in May and October. Phillips (1960) reported a similar pattern and suggested that leaf lengths in this species correspond with water temperatures. The transient summer depression of leaf lengths we observed coincided with highest water temperatures, rapidly falling salinities, and period of floral anthesis. Zieman (1975) also observed a decrease in leaf lengths during summer, but attributed it to the shunting of energy resources of the plants into the formation of sexual reproductive structures, sexual reproduction apparently decreasing the energy available for vegetative growth. Yet he stated that sexual reproduction in *T. testudinum* was not extensive. Reproductive short-shoot density estimates range 1–15% for most south and central Florida *T. testudinum* populations (Phillips 1960, Thorhaug and Roessler 1977, Grey and Moffler 1978); therefore, only a small portion of the shoots would be involved in this reproduction related sag phenomenon. In contrast, reproductive shoot densities at Lassing Park range 14–75% (Moffler et al. 1981), so a physiological shift could be substantial in this population. The entire community was exposed to the extremes of highest water temperatures and lowest salinities and our observations indicated that both vegetative and reproductive shoots exhibited summer dieback. When water temperatures approach summer maxima in Tampa Bay, *T. testudinum* leaves become soft and flaccid then break off because of protoplasmic breakdown and accelerated bacterial activity (Phillips 1960). Salinity decreases also reduce leaf growth in this species (Phillips 1960, McMillan and Moseley 1967). Therefore, the combination of

TABLE 2

Proximate analyses of transect samples of *Thalassia testudinum* from Tampa Bay, Florida. Dry weight is expressed as a percentage of fresh weight. Ash, protein, and soluble carbohydrate levels are expressed as percentage of dry weight. Means of pooled monthly collections  $\pm$  one standard deviation are listed, n = 12 for shoots and rhizomes, n = 11 for roots.

Component	Transect Sample										
	1	2	3	4	5	6	7	8	9	10	11
<b>Shoots</b>											
Dry weight	10.07	10.15	10.37	10.50	10.84	10.88	10.78	10.50	10.26	10.54	9.55
$\pm$	1.10	0.53	0.75	1.53	0.92	0.90	0.71	0.66	0.81	0.89	0.96
Ash	33.3	30.6	29.9	30.3	28.7	29.1	28.2	27.5	29.5	28.1	27.9
$\pm$	10.8	6.1	5.6	7.9	5.8	6.6	6.9	6.5	4.8	4.0	3.6
Protein	3.8	2.5	3.5	3.7	3.6	3.6	3.2	3.9	3.4	3.3	4.2
$\pm$	2.2	1.0	1.4	1.0	1.4	1.2	1.1	1.9	1.2	1.0	0.9
Carbohydrate	10.9	14.8	13.2	11.8	13.2	14.2	14.4	13.4	13.5	14.9	12.6
$\pm$	2.4	4.4	2.6	4.0	3.3	3.2	4.2	4.4	3.6	4.8	3.4
<b>Rhizomes</b>											
Dry weight	16.32	16.10	16.55	15.99	15.41	16.61	16.32	16.12	16.04	16.25	16.22
$\pm$	0.99	1.14	0.86	0.77	2.37	1.84	1.75	1.13	0.98	1.37	1.96
Ash	21.3	21.4	22.4	22.0	23.0	22.3	22.4	22.6	22.3	22.1	21.0
$\pm$	2.9	2.0	2.5	2.2	5.6	2.4	1.9	2.2	2.5	2.7	2.4
Protein	1.1	1.2	1.2	1.7	1.9	1.5	1.8	1.9	1.4	1.7	1.9
$\pm$	0.5	0.4	0.5	0.9	0.8	0.6	1.0	0.9	0.8	0.7	0.9
Carbohydrate	25.1	26.7	26.4	24.7	25.2	25.4	27.1	25.1	26.2	23.5	30.2
$\pm$	4.6	6.1	5.1	6.4	9.2	4.6	6.4	5.6	6.1	4.9	10.3
<b>Roots</b>											
Dry weight	13.46	12.66	12.76	12.18	12.74	12.22	12.74	12.55	12.78	12.53	13.50
$\pm$	2.18	1.57	2.15	0.97	2.16	1.88	1.25	0.92	2.41	1.16	1.90
Ash	31.1	30.2	28.3	30.7	32.0	29.9	28.9	28.5	29.7	29.2	28.4
$\pm$	6.6	7.9	2.5	3.3	6.4	4.2	4.2	4.0	5.4	5.2	8.1
Protein	3.0	4.1	4.3	4.8	4.1	4.2	4.6	4.0	4.2	4.4	3.3
$\pm$	1.4	1.2	1.5	1.0	1.1	1.6	1.2	0.8	1.3	0.9	1.0
Carbohydrate	14.5	11.1	12.10	11.7	11.0	11.0	10.9	10.6	12.3	12.0	13.2
$\pm$	2.3	1.9	2.6	2.7	3.4	2.1	3.4	2.5	2.8	2.5	2.6

environmental factors and an innate biological rhythm results in a summer dieback which may be expected annually. Minimal leaf lengths during the winter are likewise due to a combination of environmental factors. Leaf kills occur when the shoots are desiccated during extremely low tides associated with the passage of cold fronts. In addition, the plants are relatively dormant due to low water temperatures at this time, so recovery is slow.

Seasonal fluctuations in the chemical constituents of *T. testudinum* also reflected the influence of temperature and salinity on the growth characteristics of this species. Dry weight levels in shoots decreased as water temperatures and leaf lengths increased, during periods of maximal growth, then leveled off during the summer dieback, a period of limited growth. Dry weight levels in rhizomes increased from spring to summer, reflecting changes in resource allocation from shoot growth to nutrient storage in rhizomes (Dawes and Lawrence 1980). The dry weight patterns of the roots suggested a lag in seasonal growth relative to the shoots.

Ash levels in all three organs exhibited very similar seasonal patterns that corresponded to that of salinity. Lowest

ash levels in seagrasses previously have been attributed to the presence of new shoot growth, which lacks calcareous epiphytes (Harrison and Mann 1975, Dawes et al. 1979). This does not apply to the patterns we found because most epiphytes were removed from the leaf blades prior to analyses. The similarity of the seasonal patterns in above- and below-ground organs suggests the possible influence of an environmental factor. Salinity influences ash levels in other marine plants (Durako and Dawes 1980); it may also be responsible for the observed seasonal fluctuations in *T. testudinum* since the relatively high ash levels of seagrasses are due to the presence of sea salt in their aerenchyma (Dawes 1981).

Seasonal variations in carbohydrate and protein levels between above- and below-ground organs again reflected the functional relationship of shoots, rhizomes, and roots. Rhizomes act as storage organs for nutrient reserves in *T. testudinum* (Walsh and Grow 1972, Dawes and Lawrence 1979). Increases in carbohydrate levels from spring to fall probably result from the translocation of photosynthate in the form of starch from shoots to rhizomes (Dawes and Lawrence 1979). Carbohydrate levels were always highest

in rhizomes while protein levels, which were relatively low due to the inclusion of both living and dead tissue in our samples, were always highest in shoots and roots. These patterns exemplify the partitioning of biosynthetic activity and storage among organs. They also illustrate the intermediate nature of the roots that had seasonal carbohydrate fluctuations similar to those of the rhizome, but protein and carbohydrate levels comparable to those of the shoots. Patriquin (1972) suggested nitrogen requirements for *T. testudinum* growth could be satisfied by uptake in the sediment root layer. This was determined using yield-supply correlations of leaves, rhizomes, and interstitial waters. Fixation of molecular nitrogen in the rhizosphere seems to be responsible for the supply of nitrogen required for observed production rates (Patriquin and Knowles 1972, Capone et al. 1979). Our observations of relatively high protein levels in the roots may reflect the conversion of fixed nitrogen into organic compounds.

#### Spatial variations

When transect data were analyzed with respect to sample position, it was evident that location had a decided effect on some of the parameters studied. We found a direct relationship between maximum leaf lengths and water depths (except at the fringe which was heavily grazed) similar to that reported by Phillips (1960), but contrary to the inverse relationship for circular beds in Biscayne Bay reported by Zieman (1972). Sediment depths are evidently the factor controlling leaf blade lengths in Biscayne Bay, since the circular patches occur over depressions in the bedrock surrounded by a thin veneer of sediments (Zieman 1972). Sediment trapping by these circular beds, evidenced by the decrease in water depth at the center of the beds, was very important for maximum development of the community. Patch beds can also form when small clumps of seagrasses grow laterally while accumulating sediments and organic matter (Kelly 1980). The circular bed at Lassing Park, which seems to conform more to the lateral growth model, had a domelike depth contour (see Figure 3) and expanded radially approximately 1 meter during the study period.

Kelly (1980) found that leaf blade cropping by herbivores forms a "halo" effect around seagrass beds. The circular bed at Lassing Park exhibited this feature, and samples obtained from the fringe had distinctive chemical patterns that reflected the influence of cropping. Highest protein and lowest carbohydrate levels were observed for fringe shoots. By cropping the leaf blades, herbivores may provide themselves with a higher energy food source. Dawes and Lawrence (1979) also observed high protein and low carbohydrate levels in experimentally cropped short-shoots of *T. testudinum* which they attributed to new leaf production. Increasing the proportion of young leaf blade tissue by cropping may be effective in increasing the efficiency of energy transfer between *T. testudinum* and herbivores. Healthy *T. testudinum* releases about 1.3% of its gross production as

dissolved organic carbon (DOC) (Brylinsky 1977). The release of DOC increases tremendously in senescent tissues. This soluble material may then be absorbed by plankton (Turner 1978) and sediment heterotrophs (Brylinsky 1977), increasing the trophic complexity of carbon transfer.

A depletion of soluble carbohydrates in *T. testudinum* rhizomes in response to defoliation has been reported (Dawes and Lawrence 1979), but we noted an increase in carbohydrate levels of the roots and the seaward fringe rhizomes. *Myriophyllum spicatum*, a freshwater macrophyte, also increases the percentage of soluble carbohydrate in the roots in response to cropping (Kimbrel and Carpenter 1981). These variable results indicate differences in allocation of proximate constituents (affecting relative proportions) rather than differences in biosynthesis.

High protein levels in fringe shoots may also be due, in part, to higher nitrogen availability in the phyllosphere of this region of the bed. Capone and Taylor (1977) found that nitrogen fixation activity of epiphytized leaves can be 20% higher at the fringe phyllosphere of a *T. testudinum* bed compared to the interior of the bed, while activity associated with intact foliage may be three times higher. This relatively high activity compensates for the less effective trapping and recycling of nitrogen from detritus at the fringe (Capone and Taylor 1977).

Rhizosphere nitrogen availability, the amount of organic matter and silt-clay in the sediments may increase with lateral distance into a seagrass bed (Fonseca 1981, Kenworthy et al. 1982). Our data indicated the proximate composition of below-ground organs may be affected by these changes in sedimentary characteristics. Ammonium regeneration is highest where organic matter in the sediments is high (Iizumi et al. 1982), and uptake of ammonium by seagrass roots is greatest in highly organic substrata (Short 1983). Thus, the high protein levels of mid-bed rhizomes and roots in *T. testudinum* may be due to increased nitrogen availability and assimilation, while elevated ash levels may indicate higher interstitial salinities or solute concentrations resulting from increases in organic and inorganic ions.

#### CONCLUSIONS

Spatially related parameters can influence seasonal fluctuations in chemical constituents of *Thalassia testudinum*. Although seasonality dominated changes in the levels for most chemical constituents, others, such as shoot dry weight and root protein levels, were significantly affected spatially but not temporally. In addition, some constituents that exhibited significant seasonal fluctuations had distinctive patterns between fringe and mid-bed samples. Therefore, the presence of gradients across seagrass beds needs to be considered in future investigations of these communities.

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# Gulf Research Reports

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Tanaidacea (Crustacea: Peracardia) of the Gulf of Mexico. IV. On *Nototanoides trifurcatus* Gen. Nov., Sp. Nov., with a Key to the Genera of the Nototanaidae

Jurgen Sieg  
*Universitat Osnabruck*

Richard W. Heard  
*Gulf Coast Research Laboratory*

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TANAIDACEA (CRUSTACEA: PERACARIDA) OF THE GULF OF MEXICO.  
IV. ON *NOTOTANOIDES TRIFURCATUS* GEN. NOV., SP. NOV., WITH A KEY  
TO THE GENERA OF THE NOTOTANAIDAE

JÜRGEN SIEG<sup>1</sup> AND RICHARD W. HEARD<sup>2</sup>

<sup>1</sup>Universität Osnabrück, Abt. Vechta, Driverstraße 22, D-2848 Vechta,  
Federal Republic of Germany

<sup>2</sup>Parasitology Section, Gulf Coast Research Laboratory,  
Ocean Springs, Mississippi 39564

**ABSTRACT** *Nototanoides trifurcatus* gen. nov., sp. nov. is described and illustrated from the Gulf of Mexico. *Nototanoides* differs from the other genera of the family by the male possessing a vestigial maxilliped. It most closely resembles the genera *Nototanais* and *Androtanais*. In addition to the differences of the maxillipeds the males of *Nototanoides* can be separated by the 4-segmented antenna 1 and the females are distinguished by the trifurcate spine on the second segment of the palp of the maxilliped. A key to known genera of the family Nototanaidae is presented.

Sieg and Heard (1983) reported the tanaidacean *Teleotanais gerlachi* Lang, 1956, from the west coast of Florida, constituting the first record of the family Nototanaidae Sieg, 1976, from the Gulf of Mexico. Recently, specimens of a second member of this family, representing a new genus and species, have been made available to us by David K. Camp and Eric N. Powell. These specimens were collected on hard bottoms in both the eastern and western Gulf of Mexico.

*Nototanoides* gen. nov.

**Diagnosis** — With eyelobes; antenna 1 of female 3-segmented, in male 4-segmented. Female mandible with strong *pars molaris*; endite of maxilla 1 with 9 terminal spines, palp with 2 setae distally; maxilliped without coxa, basis fused medially, endite also fused medially. Males with mandibles, maxilla 1, maxilla 2, and labium greatly reduced, unrecognizable; maxilliped vestigial with basis and endite fused medially; epipharynx present. Female marsupium formed by 4 pairs of oostegites. Sexual dimorphism of cheliped not well marked, but distinctly larger in male. Pereopods 4–6 with dactylus and terminal spine coalesced to claw. Five pairs of pleopods, endopod with distal setae on inner margin. Uropods biramous, endopodite 2-segmented.

Type-species: *Nototanoides trifurcatus* sp. nov.

Gender: Masculine.

**Etymology** — The ending -oides indicates that this genus is related to *Nototanais* Richardson, 1906.

**Remarks** — *Nototanoides* is placed in the family Nototanaidae because the basis of the maxilliped is fused medially, the dactyl and terminal spine of pereopods 4–6 are coalesced to form a claw, the uropodal endopod is only 2-segmented and the eyelobes are well developed. It is excluded from the Leptocheliidae Lang, 1973, because the

members of that family are characterized by having an unfused maxilliped and the endopod of the uropod consisting of 3 or more articles (see Sieg 1984a). *Nototanoides* cannot be included in the Paratanaidae Lang, 1949, because the members of this family have the basis as well as the endite of the maxilliped typically enlarged and the male differs totally in body shape from the female.

The general body structure, armament of pereopods, and general shape of antenna 1 indicate that *Nototanoides* is most closely related to the nototanaid genera *Androtanais* Sieg, 1973, and *Nototanais*. *Androtanais*, known only from the male, is characterized by having (1) antenna 1 with 5 articles, (2) only remnants of the maxilla present, and (3) a nearly normally developed maxilliped (only the endite reduced) with medially fused basis. The male "cheliped" of *Androtanais* indicates sexual dimorphism, unless the female is atypical for the family. This opinion is supported by the fact that the male "cheliped" of *Androtanais* is subchelate while in the known females of the other nototanaid genera it is chelate. In *Nototanais* the male also has an antenna 1 of 5 articles, but the third article is much shorter than in *Androtanais*. *Nototanais* is also characterized by having a relatively normal maxilliped with the endite unfused. Sexual dimorphism of the cheliped is quite apparent. In males development of the propodus, fixed finger, and sometimes the carpus is much more pronounced and enlarged than in females. *Nototanoides* differs from *Androtanais* and *Nototanais* by the male having an antenna 1 with 4 articles (third article very small), less sexual dimorphism of the chelipeds (the male cheliped is much larger and stronger than that of the female but otherwise similar), and a strongly reduced male maxilliped (basis small and fused medially, palp lacking, endite fused). In the female of *Nototanoides*, the endite of maxilla 1 has only 9 terminal spines instead of 10 as in *Nototanais*. As in *Androtanais*, the endite of the maxilliped is almost totally fused in *Nototanoides*. By contrast, males of *Nototanoides* and *Nototanais* have greatly reduced mouthparts with only the reduced palp of maxilla 1 remaining.

## KEY TO THE GENERA OF THE FAMILY NOTOTANAIDAE

1. Antenna 1 with more than 4 articles (mouthparts reduced except maxilliped) . . . . . 2
- Antenna 1 with at most 4 articles . . . . . 4
2. Antenna 1 with 8 articles (peduncle with 3 and flagellum with 5 articles), body extremely attenuated . . . . . *Tanaissus* Norman and Scott (males)
- Antenna 1 with 5 articles, body not extremely attenuated . . . . . 3
3. Last 3 joints of antenna with groups of aesthetascs, third joint annular . . . . . *Nototanais* Richardson (males)
- Only the last joint bearing one aesthetasc distally, third joint elongate . . . . . *Androtanais* Sieg (males)\*
4. Antenna 1 with 4 articles . . . . . 5
- Antenna 1 with 3 articles . . . . . 6
5. Second and third segments of antenna subequal, third segment lacking aesthetascs, mouthparts present . . . . . *Teleotanais* Lang (females)\*\*
- Third segment of antenna 1 annular, distinctly shorter than second segment, with a group of aesthetascs; mouthparts including the maxilliped reduced . . . . . *Nototanoides* gen. nov. (males)
6. Pleopods well developed . . . . . 7
- Pleopods reduced . . . . . *Metatanais* Shiino (females)\*\*
7. Eyelobes present . . . . . 8
- Eyelobes absent . . . . . 9
8. Maxilliped with endite unfused medially, a short seta near articulation of palp, segment 2 of palp with ciliate spine; maxilla 1 with endite bearing 10 terminal spines . . . . . *Nototanais* (females)
- Maxilliped with endite fused proximally, only distal third unfused, 1 long seta near articulation of palp, segment 2 of palp with strong trifurcate spine; maxilla 1 with endite bearing 9 terminal spines . . . . . *Nototanoides* gen. nov. (females)
9. Endite of maxilliped fused medially . . . . . *Tanaissus* (females)
- Endite of maxilliped unfused medially . . . . . *Prototanais* Sieg (females)\*\*

\*Female unknown

\*\*Male unknown

*Nototanoides trifurcatus* sp. nov.

216179; 2 ♂♂, off Texas coast, Sackett Bank, 100 m, 28°38'01"N, 89°33'22"W, USNM 216180; Project Hour Glass (Florida West Coast): 1♀, Sta. L, 26°24'00"N, 83°22'00"W, 54.9 m, USNM 216182; Sta. D, 27°37'00"N, 83°28'00"W, 36.6 m, 1 ♀, USNM 216182; Sta. E, 27°37'00"N, 84°13'00"W, 73.2 m, 2 ♀♀, USNM 216182; Sta. C, 27°37'00"N, 83°28'00"W, 36.6 m, 1 ♀ + 1 ♂, FSBC-I-31419, 2 ♀♀ + 1 ♂, FSBC-I-31418; BLM Mississippi-Alabama-Florida Study: Sta. 2207, 27°57'00.4"N, 83°09'00.3"W, 19 m, 1 juv.; Sta. 2423, 29°37'00.8"N, 84°17'00.2"W, 19 m, 1 ♀; Sta. 2852, 28°30'00.4"N, 83°29'58.4"W, 22 m, 1 juv. + 1 ♀, all USNM 216183.

*Description of female (paratype) (Figs. 1-7).*

*Body* — Length of adult females from 3.0–3.5 mm; subadults and manca stages smaller; somewhat less than 5.5 times longer than broad (Fig. 1).

*Allotype* — Male, National Museum of Natural History, USNM 222508; same locality as holotype.

*Paratypes* — 1 ♀ + 2 ♂♂ in collection of Sieg and 16 ♀♀, 5 ♂♂, 1 manca-III, USNM 222509; same locality as holotype; 8 ♀♀ + 2 neuters, USNM 216175; East Flower Garden Bank, 120 m, 22 June 1975; 6 ♀♀ + 3 ♂♂, East Flower Garden Bank, Gollums Lake, Sta. 80-19, USNM 216176; 1 neuter, 1 ♀, 2 ♂♂, same locality, Sta. 80-R9, USNM 216177; 1 ♀, East Flower Garden Bank, Dive 6, USNM 216178.

*Additional material* — Texas Hard Bank Study: 1 ♀, Geyor Bank, 27°49'24"N, 93°03'42"W, 190 m, USNM

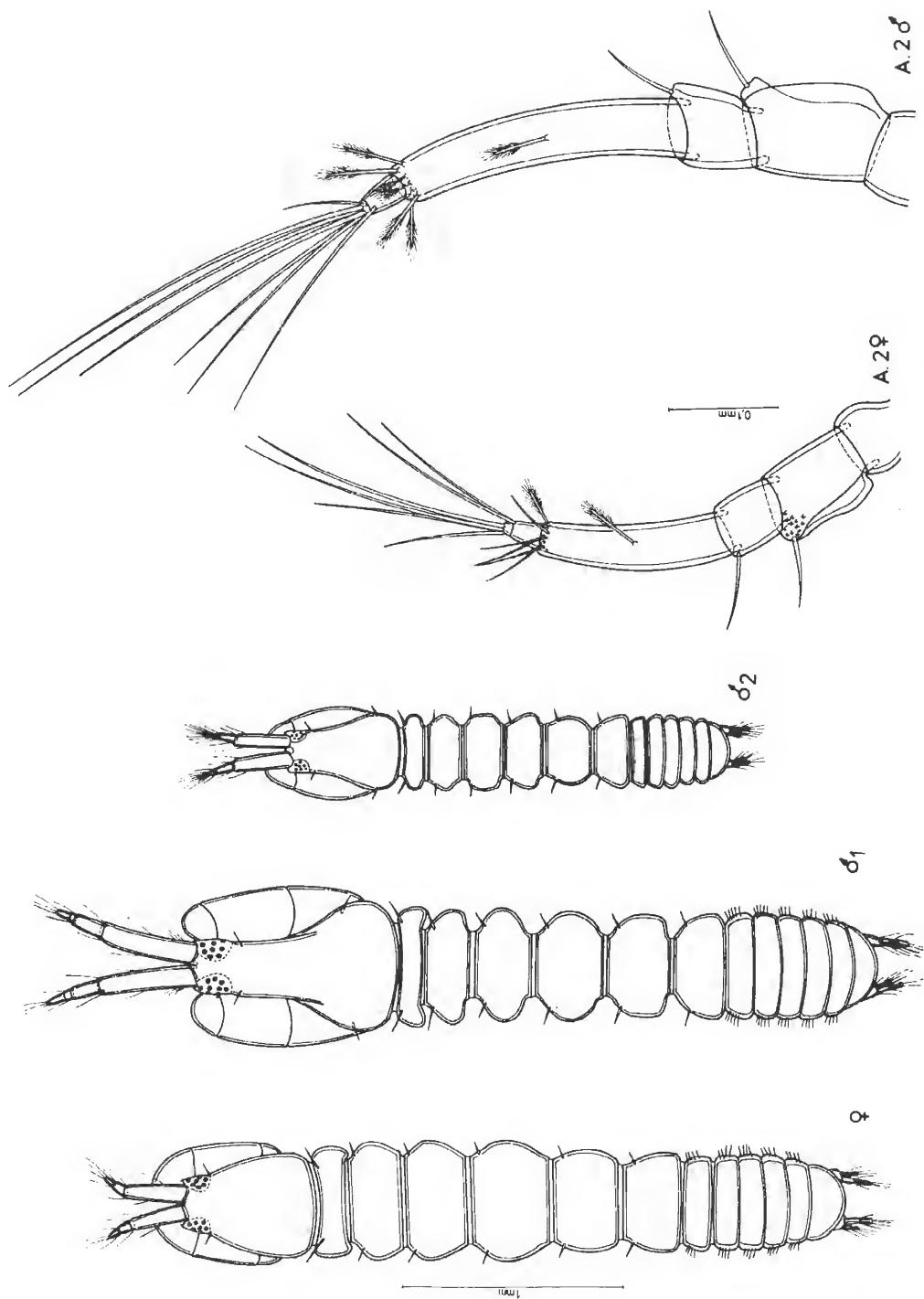


Figure 1. *Nototanoides trifurcatus* gen. nov., sp. nov. Dorsal aspect of female, male 1 and male 2 (pereopods excluded); Antenna 2 (A.2) of female and male.

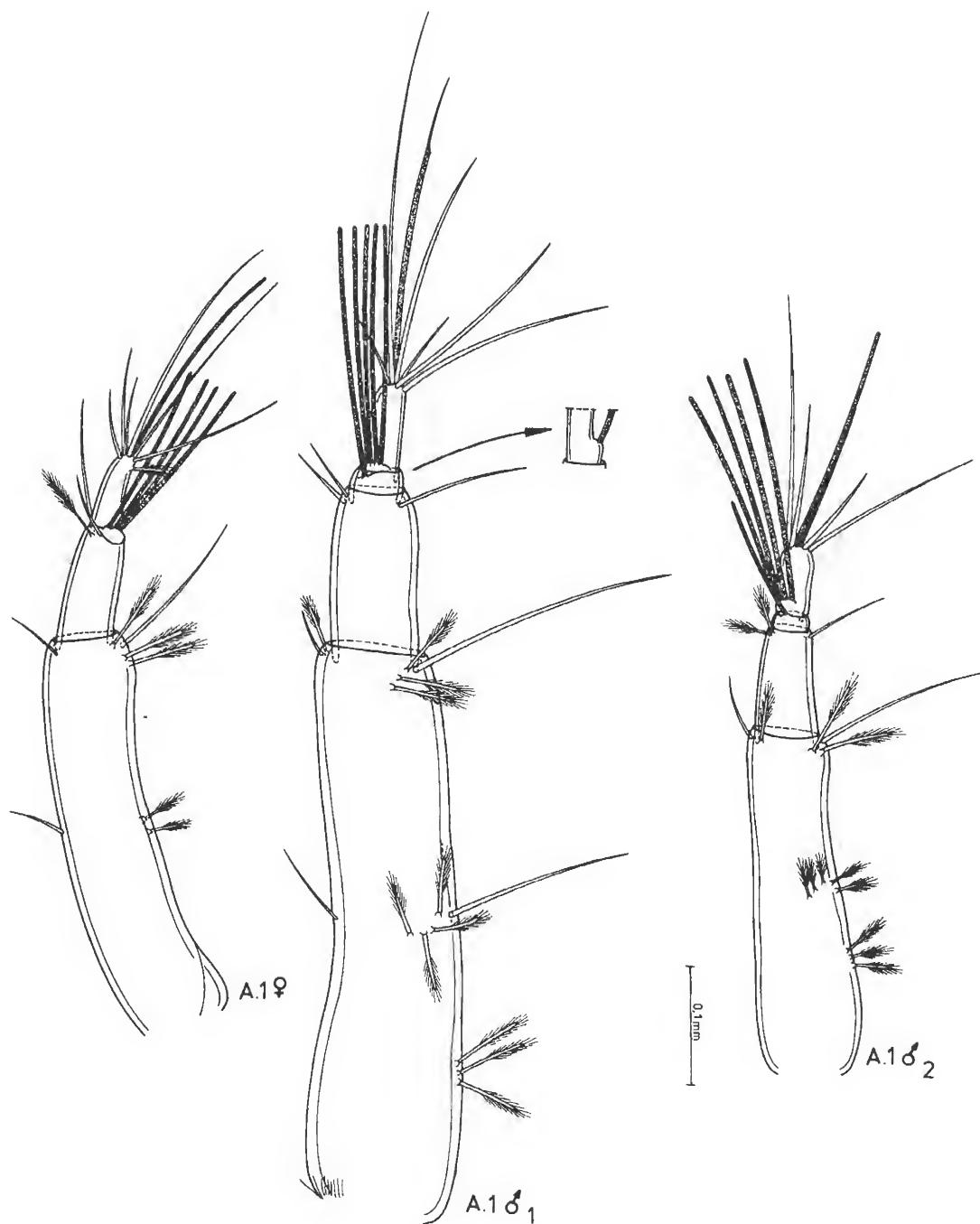


Figure 2. *Nototanoides trifurcatus* gen. nov., sp. nov. Antenna 1 (A.1) of female, male I and male 2.

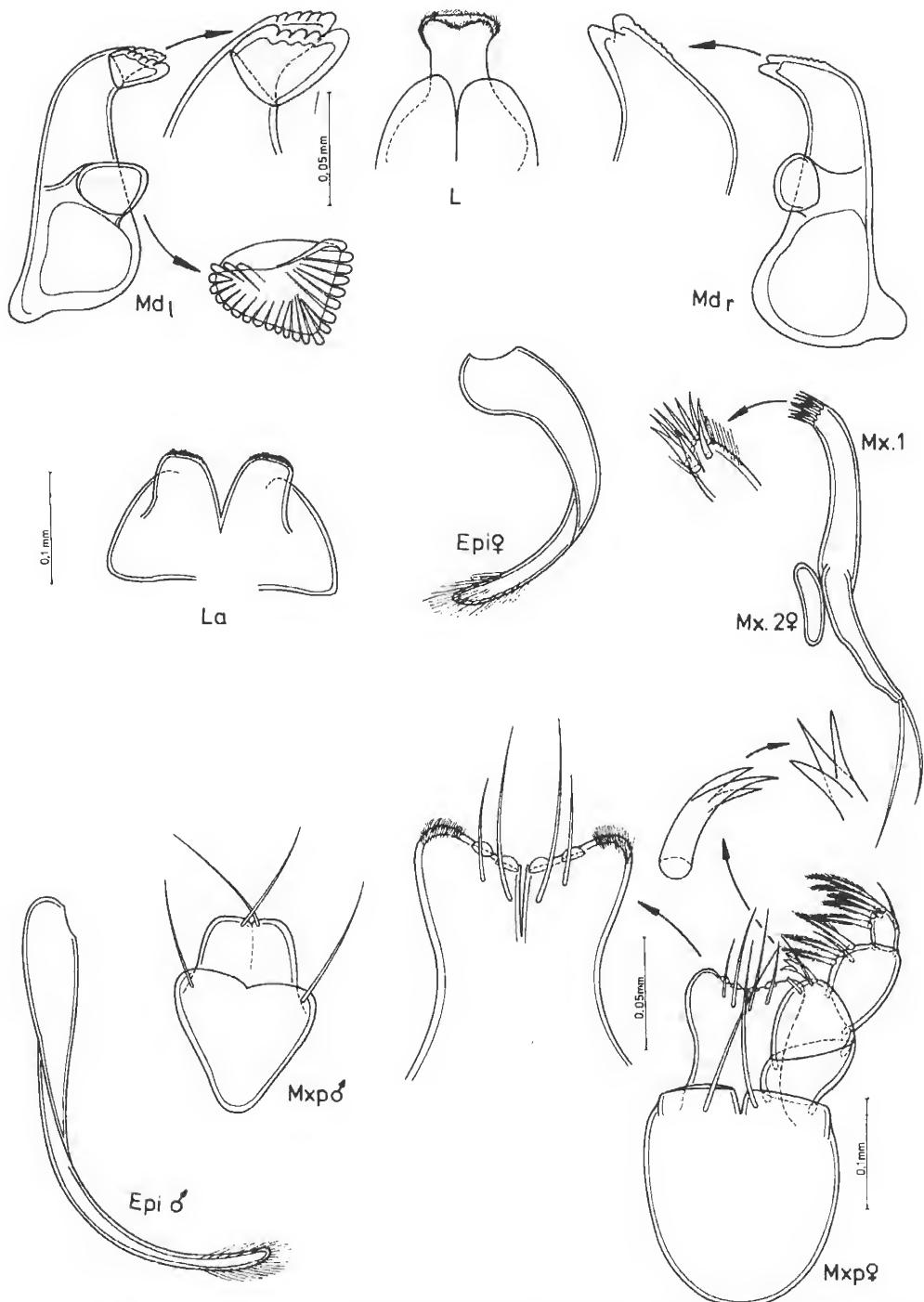


Figure 3. *Nototanoides trifurcatus* gen. nov., sp. nov. Female: right (Md r) and left (Md 1) mandibles, labium (L), epipharynx (Epi), maxilla 1 (Mx. 1) and maxilla (Mx. 2), labrum (La), and maxilliped (Mxp). Male: epipharynx and maxilliped.

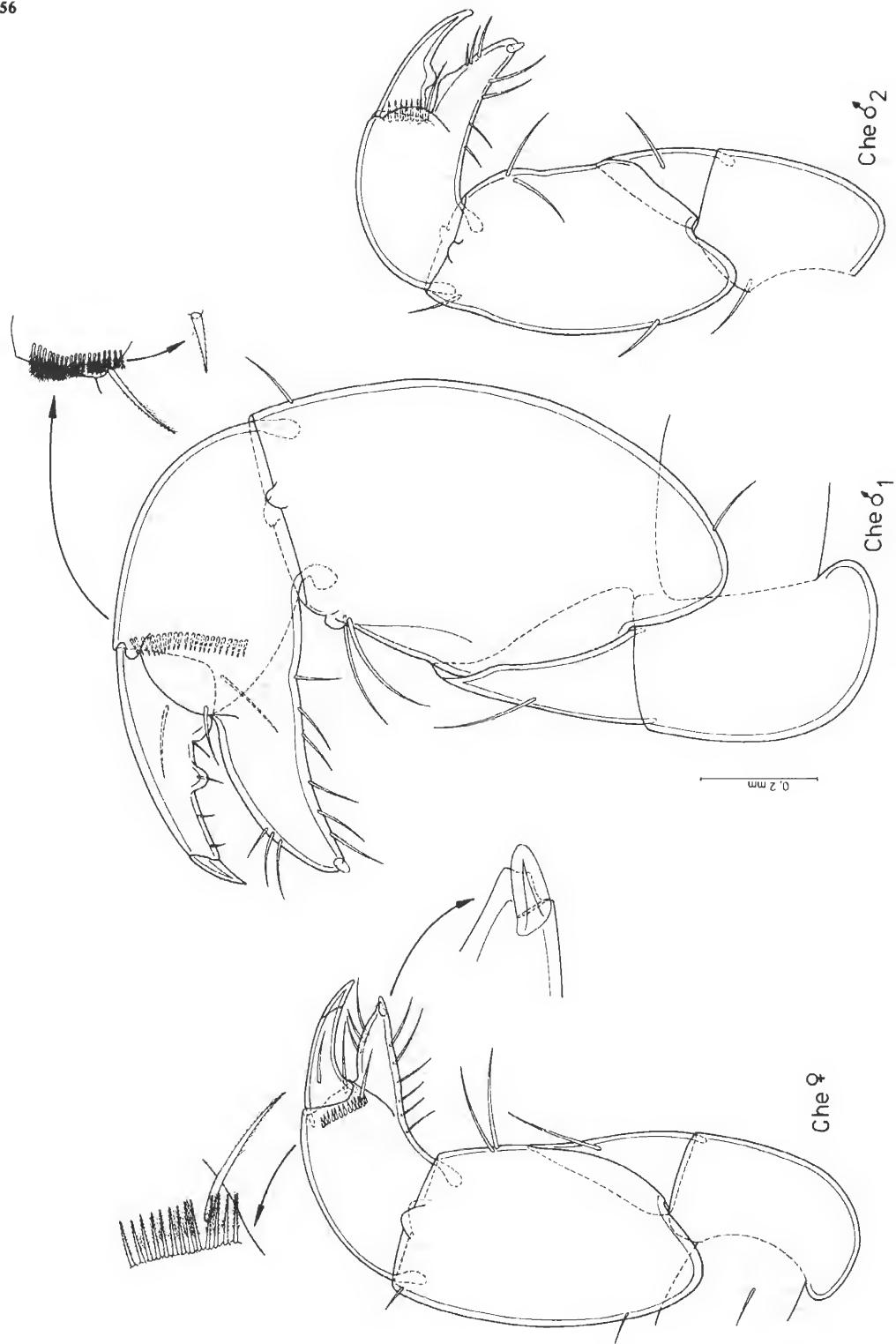


Figure 4. *Notoranooides trifurcatus* gen. nov., sp. nov. Chelipeds (Che) of female, male 1 and male 2.

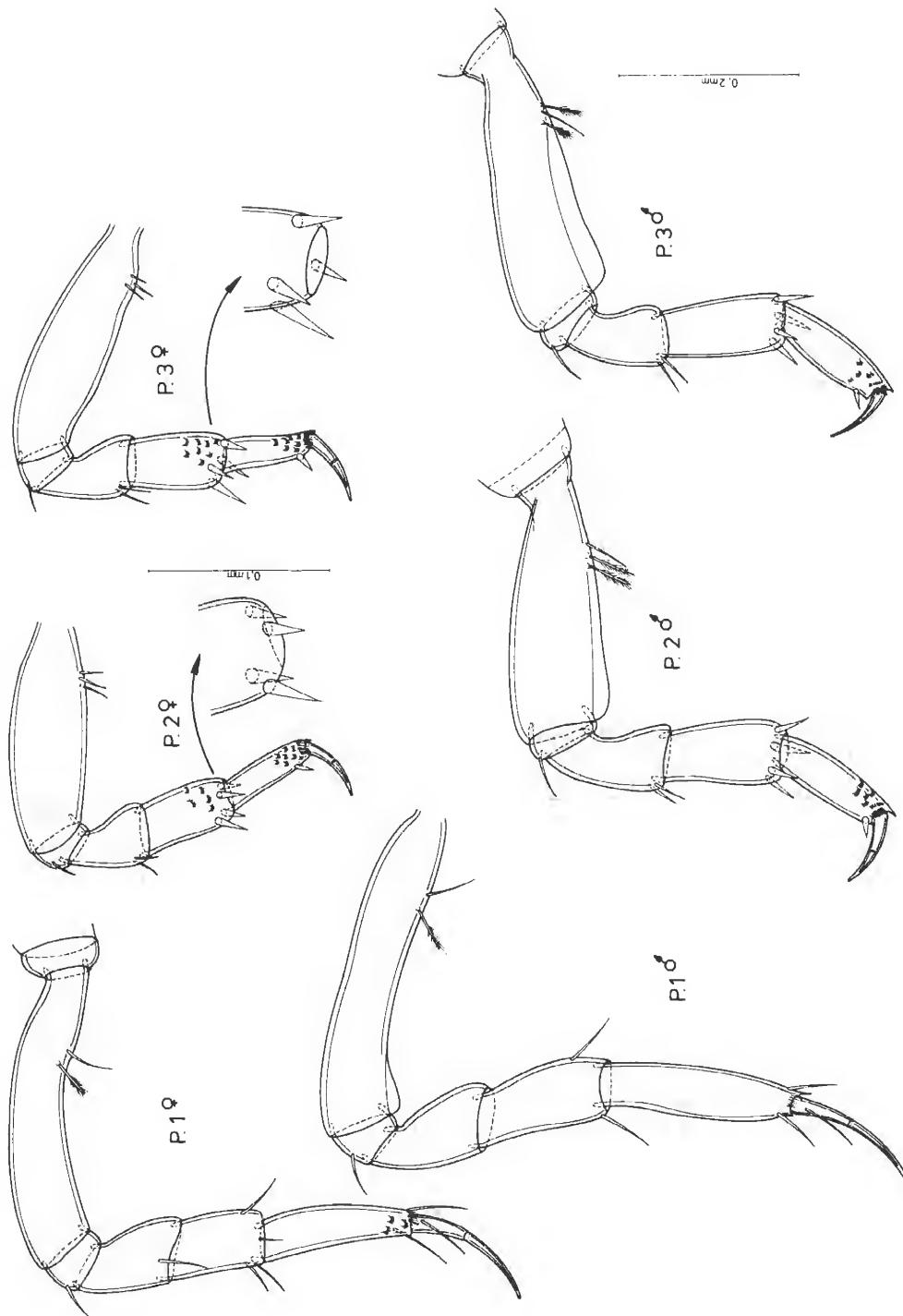


Figure 5. *Nototanoides trifurcatus* gen. nov., sp. nov. Pereopods 1-3 of female and male.

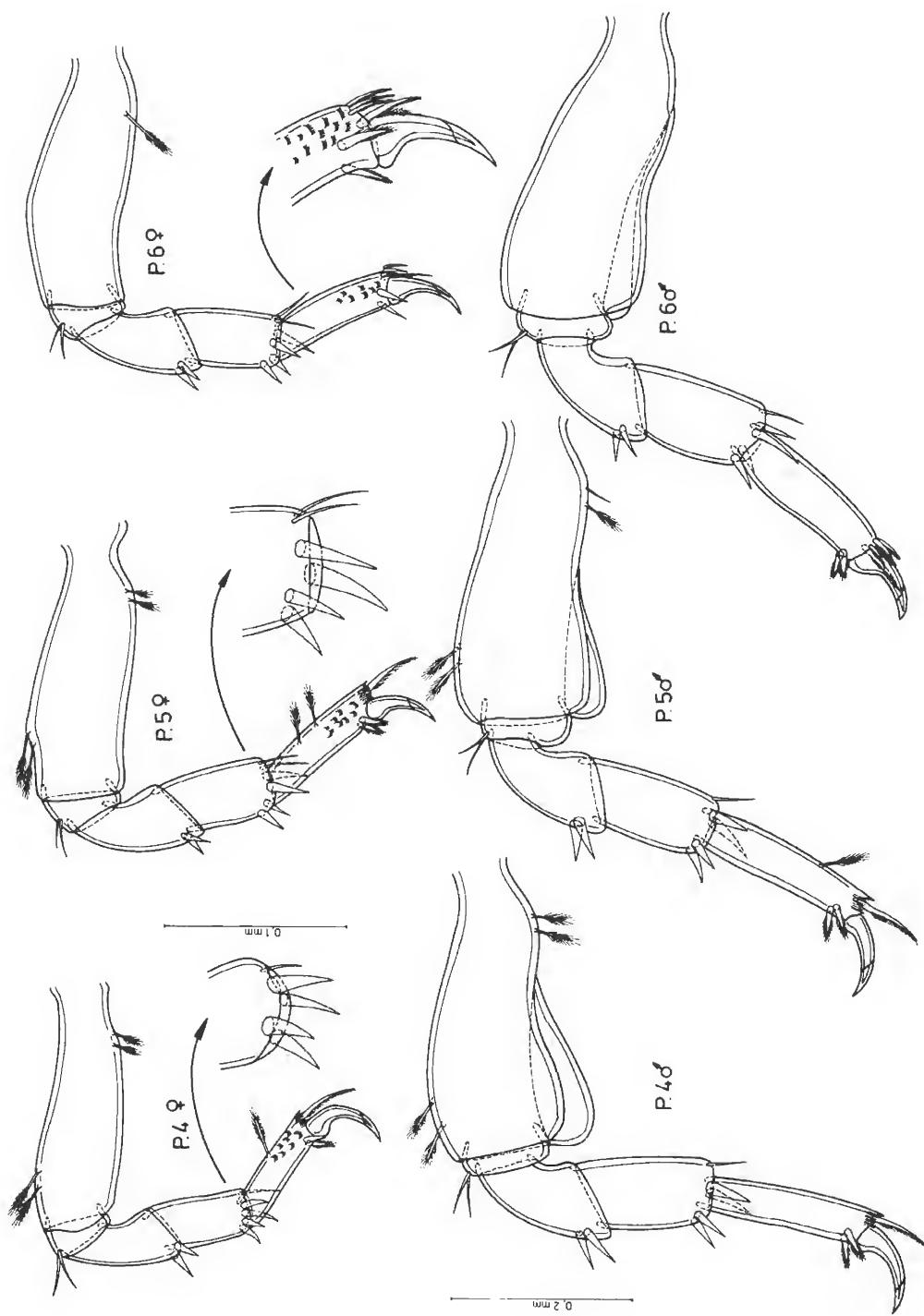


Figure 6. *Nototanoides trifurcatus* gen. nov., sp. nov. Pereopods 4-6 of female and male.

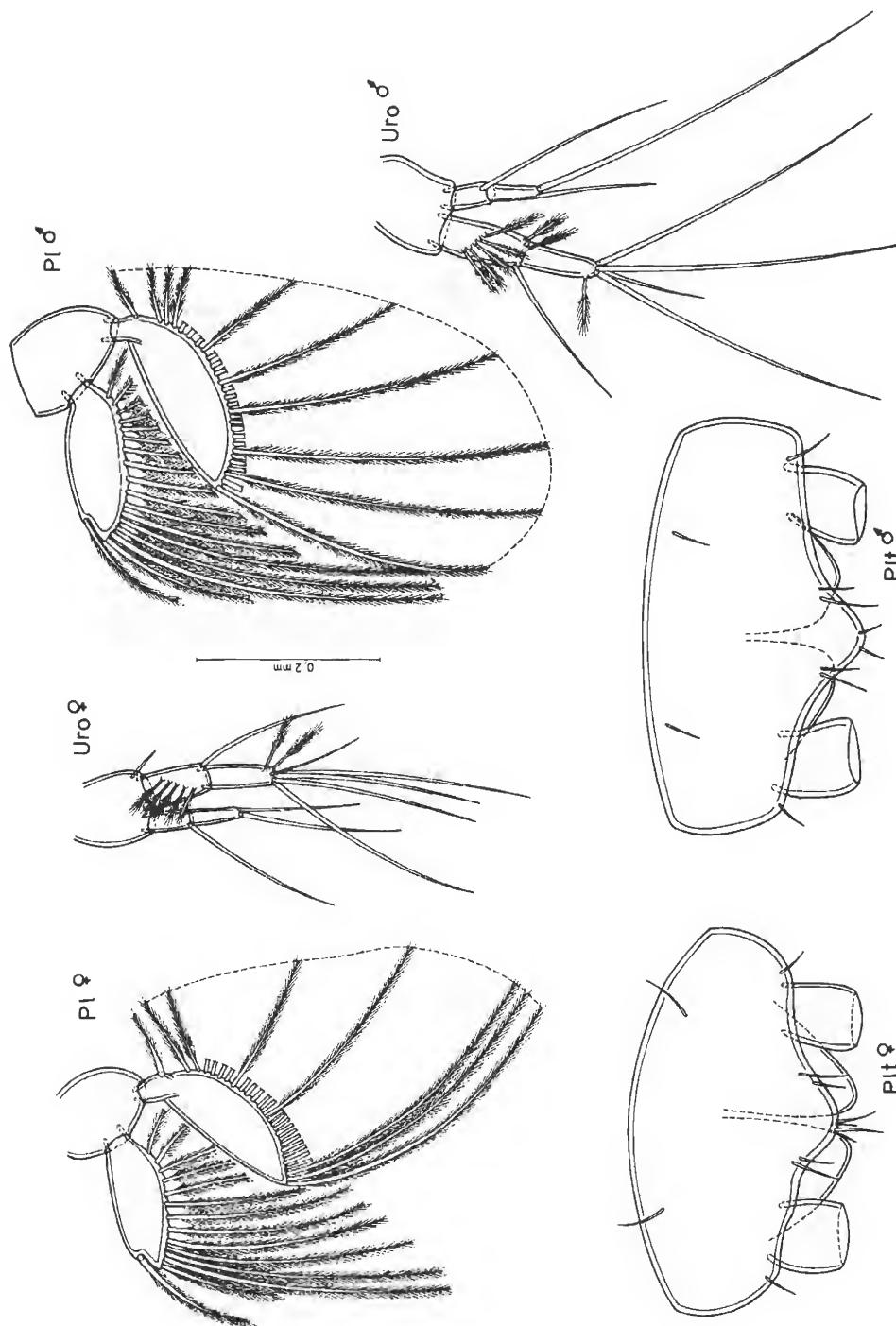


Figure 7. *Nototanoides trifurcatus* gen. nov., sp. nov. Female and male pereiopods (Pl), uropods (Uro), and pleotelson (Plt).

**Cephalothorax** — Elongate, nearly 1.3 times longer than broad, gently rounded posteriorly and narrowed anteriorly, cyclobes relatively large, single small seta on lateral margin immediately posterior to each eyelobe, rostrum indistinct.

**Pereonites** — All pereonites with one seta at anterior corner, lateral borders rounded with no spines or processes; first pereonite about 3.6 times broader than long, anterior and posterior border smooth, concave; second slightly more than 2 times as broad as long; third approximately 1.9 times as broad as long, greatest width in anterior half; fourth 1.5 times as broad as long; fifth 1.7 times broader than long; sixth 1.8 times broader than long, greatest width in posterior third.

**Pleonites** — 5 tergites visible dorsally, all of same size, each nearly 4 times broader than long, each segment armed laterally with 2–5 small setae.

**Antenna 1** (Fig. 2) — 3-segmented; segment 1 longer than remaining 2 combined, nearly 4 times longer than broad, slightly curved sternally (ventrally), midsternally with 1 plumose seta, and distally with 3 strong plumose setae and 1 long naked seta, tergal border with 1 seta in the middle and distally; second segment smaller, about 2 times longer than broad, sternal margin distally with 4 aesthetascs, tergal margin with 2 naked setae and 1 plumose seta distally; third segment relatively small, but 2.3 times as long as broad, distally with 1 aesthetasc, 3 long and 3 short naked setae, and 1 plumose seta.

**Antenna 2** (Fig. 1) — 6-segmented; first segment small, as long as broad, partly fused with cephalothorax; second relatively large, laterally depressed with tergal border flattened, nearly 1.5 times as long as broad, tergal margin with 1 seta, and some groups of minute setae distally; third, as long as broad, with 1 seta distally at tergal margin; fourth segment elongate and curved medially, 4 times as long as broad, with 1 plumose seta medially, and 5 naked setae as well as 1 plumose seta distally; fifth small, as long as broad, with 2 long setae distally; sixth minute, conical, with 1 short and 3 longer setae.

**Labrum** (Fig. 3) — Hood-shaped, covered with very fine setae.

**Mandibles** (Fig. 3) — Robust, *pars molaris* well-developed, having crushing area surrounded with strong raised margin,  $\frac{3}{4}$  of margin notched; left mandible with strong crenulate *lacinia mobilis* and well-developed *pars incisiva*; right mandible without *lacinia mobilis* (fused with the *pars incisiva*?), with strong bifid crenulate *pars incisiva*.

**Labium** (Fig. 3) — With inner and reduced outer lobe; inner lobe deeply incised in middle, distal part covered with groups of very small setae.

**Maxilla 1** (Fig. 3) — With endite and uniarticulate palp; endite with 9 normal spines; palp nearly as long as endite, with 2 relatively short setae.

**Maxilla 2** (Fig. 3) — Of normal size for family, oval, lacking setae.

**Maxilliped** (Fig. 3) — Without coxae, well-developed;

basis fused medially, with 1 long seta near articulation of palp; endite of normal size, distal third unfused medially, each side with 2 distal setae, 2 membranous hemispherical structures, and very small setae on distolateral margin. Palp with 4 articles; first article slightly longer than broad, without setae; second triangular, outer margin with 1 seta, inner margin with 2 setae and 1 strong, 3-pointed ("trifurcate") spine; third segment 1.25 times longer than broad, inner border with 3 serrate setae and 1 naked seta; fourth small, with 1 short seta on outer border, and 5 serrate setae on inner border.

**Epignath** (Fig. 3) — Falciform, with minute hairs at tip.

**Cheliped** (Fig. 4) — Strongly developed; sidepiece large, behind proximal conjunction of basis; latter 1.8 times longer than broad, no seta; merus triangular, elongate, and reaching nearly to middle of carpus, 1 rostro-sternal seta; carpus 1.7 times longer than broad, tergal border with 1 distal and 1 proximal seta, sternal border with 1 rostral and 1 caudal posterior seta; propodus of normal size, fixed finger with strong spine at tip, tergal border with 3 rostral setae, sternal border with 6 rostral setae, caudally with 1 seta near articulation of dactylus, comb consisting of 13 (variable) short, serrated setae and 1 long serrate seta; dactylus curved, tip strongly calcified and colored more or less dark brown, 1 rostral seta.

**Pereopod 1** (Fig. 5) — Slender, coxa small, not fused with pereonite, without setae; basis slender, 3.7 times longer than broad, tergal border with 1 rostral naked seta and 1 plumose seta; ischium small, with 1 tergal seta; merus elongate, 1.25 times longer than broad, sternal border with 1 rostral seta distally; carpus 1.7 times longer than broad, distally with 1 rostral and 1 caudal seta sternally as well as tergally; dactylus with spine, nearly as long as propodus, with 1 small seta proximally.

**Pereopod 2** (Fig. 5) — Coxa small, not fused with pereonite, without setae; basis nearly 3 times as long as broad, sternal border with 3 short setae proximally; ischium small, with 1 tergal seta; merus 1.2 times longer than broad, tergal border distally with 1 rostral and caudal seta; carpus 1.7 times longer than broad, distally with 1 rostral and caudal spine tergally as well as sternally, sternal third with groups of tiny setae; propodus 3.3 times longer than broad, tergal border with 1 spine distally; dactylus curved, reaching approximately 2/3 length of propodus.

**Pereopod 3** (Fig. 5) — Proportion and armament as in P.2, but carpal spines slightly larger.

**Pereopod 4** (Fig. 6) — Coxa fused with pereonite; basis 3 times longer than broad, sternal border with 2 plumose setae proximally and tergal border with 2 plumose setae distally; ischium small, with 2 tergal setae; merus nearly 2 times longer than broad, distally with 1 rostral and 1 tergal spine sternally and tergally, 1 distal seta at sternal border; propodus 3 times longer than broad, distally tergal margin with 1 rostral and 1 tergal spine, sternal margin with feathered hair in middle and 1 long distal seta, distal third

with groups of minute setae; dactylus and spine fused as claw, half as long as propodus.

**Pereopod 5** (Fig. 6) — Proportions and armament as in P.4; except merus, bearing distally 1 rostral and 1 caudal seta on sternal border, and propodus bearing 2 plumose setae.

**Pereopod 6** (Fig. 6) — Proportions and armament as in P.4 and P.5, except for propodus bearing 1 large spine and 3 additional short spines at sternal border distally.

**Pleopods** (Fig. 7) — All 5 pairs of pleopods similarly developed; basis nearly as long as broad, without setae; exopod uniarticulate, without setae on inner border, with many setae on outer border, most proximal 1 stouter than others, separated by gap from them; endopod uniarticulate, with 1 seta at distal inner border, many setae on outer border.

**Pleotelson** (Fig. 7) — Normally developed, slightly more than twice as broad as long, caudal lobe prominent, with 2 small and 2 longer setae, with 2 setae medial to, and 1 seta lateral to, articulation of uropod; 2 additional setae near border with fifth pleonite.

**Uropods** (Fig. 7) — Short, biramous. Protopod (basis) developed normally, 1.25 times longer than broad, with 1 small seta near articulation of exopodite. Endopodite short, 2-segmented; first segment with 1 long seta distally; second segment with 2 long setae at tip. Exopodite 2-segmented; first segment about twice as long as broad, with oblique row of 5 plumose setae, and 1 long distolateral seta; second segment nearly 3 times as long as broad, with 1 short naked seta, 2 plumose setae, and 4 long setae at tip.

*Description of male Type 1 (paratype) (Figs. 1–7).*

**Body** — Length of “adult” males (= copulatory ♂ Type B? of Sieg 1984) 3.2–3.7 mm; approximately 6 times longer than broad, shape different than that of the female (Fig. 1).

**Cephalothorax** — Elongate, approximately 2/5 total length of animal, anterior half laterally compressed, borders parallel, eyelobes large, with small seta adjacent to it, posterior half strongly inflated, bearing carapace fold, 1 small seta present.

**Pereonites** — All 6 pereonites with 1 seta on anterior corner, borders much more rounded than in female; first pereonite small, nearly 4.5 times longer than broad, anterior and posterior border smoothly concave; second and third pereonites about 2.6 times and 1.8 times broader than long, respectively, with lateral borders strongly convex; fourth and fifth pereonites 1.7 and 1.6 times broader than long, respectively, with anterior and posterior part laced, lateral borders convex; sixth twice as broad as long, only anterior part laced.

**Pleonites** — Similar to female, but only 3 times broader than long.

**Antenna 1** (Fig. 2) — 4-segmented, elongate, much stronger than female; first article longer than remaining ones, 4.5 times longer than broad, sternal margin with 3 plumose setae at proximal 1/3, with 4 plumose setae and 1

long seta in middle and with 3 plumose setae and 1 long seta distally, tergal border with 1 seta in middle and 1 seta and 1 feathered hair distally; second segment 1.8 times longer, distally with 2 small setae tergally and 1 longer seta sternally; third segment small, annular, with 1 aesthetasc; fourth segment 2.3 times longer than broad at the basis with scale bearing 4 aesthetascs, with 1 additional aesthetasc, 4 longer and 2 shorter setae distally.

**Antenna 2** (Fig. 1) — Similar to female, except for some minor differences distally (plumose setae instead of naked setae at distal end of antepenultimate segment).

**Mouthparts** — Greatly reduced, vestigial.

**Maxilliped** (Fig. 3) — Strongly reduced; basis small, fused medially, with 1 long seta distally on each side (near original articulation of palp); palp missing; endite totally fused, with 2 long setae distally.

**Epignath** (Fig. 3) — As in the female, but larger.

**Cheliped** (Fig. 4) — Much larger than in female, with carpus much more voluminous; propodus with reduced spine at tip of fixed finger, comb more developed, consisting of about 22 short and 1 long setae; dactyl with rounded tooth.

**Pereopods 1–6** (Figs. 5–6) — Proportions and armament, except for basis, as in female; basis of all pereopods stronger than in female, thickness of basis increasing from P.1–P.6, especially in P.4–P.6, rostral and caudal part of sternal margin prominent, U-shaped in cross section forming groove for carpus and propodus when leg is retracted.

**Pleopods, uropods** (Fig. 7) — As in female.

**Pleotelson** (Fig. 7) — Shorter than in female, 2.5 times broader than long; armament as in female.

*Description of male Type 2 (paratype) (Figs. 1–2, 4).*

**Body** (Fig. 1) — Distinctly smaller, length approximately 2 mm; cephalothorax more elongate as in female, but less than in “adult” male (male 1 stage), anterior half laterally compressed; shape of pereonites similar to female.

**Appendages** — Antenna 1 (Fig. 2) similar to “adult” male Type 1, but proportionally smaller; mouthparts reduced, maxilliped also reduced; cheliped small (Fig. 4), more like that of female; pereopods, pleopods, and uropods similar to the “adult” male.

**Remarks** — The morphological comparisons have already been made in the discussion of the relationship of *Nototanoides* to other nototanaid genera. Based on the work of Sieg (1984a), it appears that the male Type 1 and male Type 2 of *Nototanoides* correspond to the “primary male” and “secondary male” (type B and C), respectively. *Nototanoides trifurcatus*, like species of *Nototanais*, appears to follow the type of protogynous development (Sieg 1984b) represented by *Heterotanais oerstedi* (Krøyer, 1842). Like the males of *Nototanais*, those of *Nototanoides* have chelipeds that differ morphologically only slightly from those of the females. Additional male forms can be recognized only by their measurements.

**Ecological Notes** — The specimens of *Nototanoides trifurcatus* examined during this study came from carbonate sands and rocks in depths ranging from 19 to 190 m. Off the Texas coast (East Flower Garden Bank), large populations of this and at least 10 other tanaidacean species were associated with a natural anoxic, sulfurous brine seep. For detailed discussion of this unique habitat, see Powell et al. (1982).

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## Yield-Per-Recruit of Spotted Seatrout

Richard E. Condrey

*Louisiana State University*

Gerald Adkins

*Louisiana Department of Wildlife and Fisheries*

Michael W. Wascom

*Louisiana State University*

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## SHORT COMMUNICATIONS

### YIELD-PER-RECRUIT OF SPOTTED SEATROUT<sup>1</sup>

RICHARD E. CONDREY<sup>2</sup>, GERALD ADKINS<sup>3</sup>  
AND MICHAEL W. WASCOM<sup>2</sup>

<sup>2</sup>Coastal Fisheries Institute, Center for Wetland Resources, Louisiana State University, Baton Rouge, Louisiana 70803-7503

<sup>3</sup>Louisiana Department of Wildlife and Fisheries, Bourg, Louisiana 70343

**ABSTRACT** A von Bertalanffy growth curve,

$$L = 65.47 \text{ cm} (1 - e^{-0.2005(t + .4113 \text{ yr})}),$$

is derived from published data on spotted seatrout in the U.S. Gulf of Mexico and used in constructing a yield-per-recruit contour. Maximum yield-per-recruit is approached as F increases above 1 and age of first entry approaches 3.9 years (14.9 in., 1.1 lb). A linear regression is derived relating average size of capture to gill net mesh size (MS in inches),

$$L = 1.97 \text{ in.} + 8.63 \text{ MS},$$

and used along with legal sizes of first harvest to evaluate the impact of current laws in the Gulf states on yield-per-recruit of spotted seatrout.

#### INTRODUCTION

Spotted seatrout are one of the most important edible finfish in the northern Gulf of Mexico. Despite their pre-eminence, there is a perception that scientific "information [on seatrout] is general and, for the most part, inadequate" to meet management's needs (Lorio and Perret 1980). Current regulations on the size at harvest are not based upon a quantitative consideration of yield-per-recruit and spawner-recruit relationships. Rather, current laws are largely based upon expedient compromises between conflicting user groups (Perret et al. 1980; Merriner 1980).

In this note we present a yield-per-recruit analysis based entirely upon a synthesis of published data. While lacking the rigor of a study based upon its own data collection, this synthesis does offer a needed first look at the effect of current regulatory restrictions on the yield of this increasingly important resource.

#### RESULTS AND DISCUSSION

##### *Construction of the yield-per-recruit contour*

A von Bertalanffy growth curve,

$$L = 65.47 \text{ cm} (1 - e^{-0.2005(t + .4113 \text{ yr})}),$$

was fitted to size-at-age data (total length in cm) reported for seatrout in U.S. Gulf of Mexico estuaries (Pearson 1929, Klima and Tabb 1959, Moffett 1961, Stewart 1961, Tatum 1980, and Colura et al. 1984) (Figure 1). Mean annual air

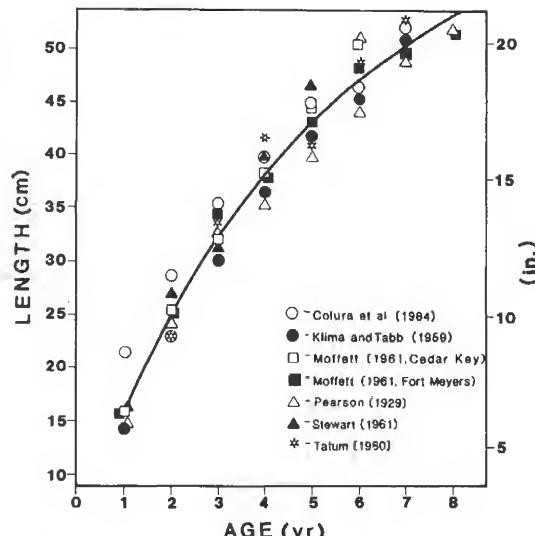


Figure 1. Growth rate of spotted seatrout in the northern Gulf of Mexico. Tatum's "Age I+ . . . Age VI+" data are plotted as age 2 through age 7 fish under the assumption that all of the annual growth had occurred when the length-age measurements were made.

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temperature (1941–1970; NOAA 1981, 1983a, b) of the coastal weather station nearest to each study site was used as an index of mean annual water temperature (Table 1). The average of these means was used as an estimate of the overall mean water temperature for the entire data set.

Use of the combined growth equation and overall mean temperature in Pauly's (1979) equation generated an instantaneous rate of natural mortality ( $M$ ) of 0.45 on an annual basis. These rates of growth and mortality predict that maximum biomass of an unfished cohort is attained at 3.9 yr (14.9 in., 1.1 lb).

Tatum (1980) reports a total annual mortality of 50% ( $Z = 0.69$ , where  $Z$  is the instantaneous annual rate of total mortality) for spotted seatrout in Alabama. An instantaneous rate of annual fishing mortality ( $F$ ) of 0.24 is estimated as the difference between Tatum's  $Z$  and our  $M$  ( $F = Z - M = 0.69 - 0.45 = 0.24$ ).

For comparison, we reran the natural mortality analysis using the individual estimates of growth and temperature. The predicted individual estimates of  $M$  ranged from 0.22 to 0.65 with a mode of 0.36 (Table 1). Maximum biomass of an unfished cohort was predicted to occur over a range of 3.4 yr (14.2 in., 1.0 lb) to 8.4 yr (24.4 in., 5.0 lb) with modes of 4.9 yr and 15.9 in. (1.3 lb) (Table 1).

We are not able to correlate the variation between these individual estimates with location or timing of the studies. For example, estimates were comparable for central and south central Texas despite the wide temporal range of these reports, 1929 and 1984. In contrast, Moffett's study generated two widely differing sets of estimates for north central and south central Florida. We assume that the real variation in growth rates which should occur as one moves from the southern to the northern estuaries of the U.S. Gulf of Mexico is not represented by the variation observed in these estimates. We use our combined equation as the best estimate of growth throughout the rest of this paper.

Data on the average sizes of fishes (total length in inches) caught in differing size mesh (MS in inches) of monofilament and multifilament gill nets are plotted in Figure 2 (Trent and Pristas 1977, Matlock et al. 1978, Adkins et al.

1979, Lorio et al. 1980, Adkins and Bourgeois 1982, Arnoldi 1982). Analysis of covariance indicates no significant effect of mesh type (mono- or multifilament) on the relationships between sizes of fish and mesh,

$$L = 1.97 \text{ in.} + 8.63 \text{ MS}$$

( $r^2 = 0.90$ , H.S.). The minimum legal mesh sizes of gill nets in the various Gulf states (Table 2) were used in this weighted regression to estimate average size at entry.

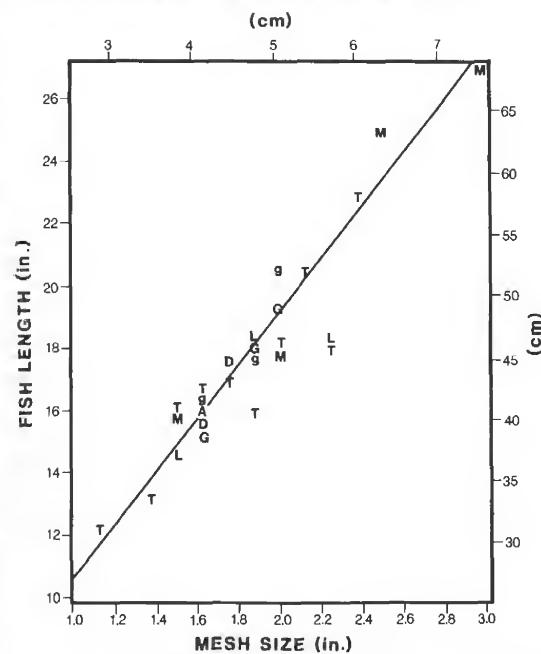


Figure 2. Relationship between mesh size of monofilament or multifilament gill nets and average length of spotted seatrout captured. Data from Matlock et al. 1978 (M); Trent and Pristas 1977 (T); Adkins et al. 1979 (A); Lorio et al. 1980 (L); Adkins and Bourgeois 1982 (G, monofilament; g, multifilament); and Arnoldi 1982 (D).

TABLE 1  
Estimates of growth, mortality, and of age and size of maximum biomass predicted for an unfished cohort.

Area of study	Author	$L_{\infty}$ cm	k annual	$t_0$ years	Temp. °C	M annual	Age years	Length in.	Wt. lb
Corpus Cristi, Texas	Pearson 1929	71.4	.148	-0.640	22.2	.36	4.9	15.6	1.3
Matagorda, Texas	Colura et al. 1984	72.6	.152	-1.288	21.4	.36	4.0	15.9	1.3
Coastal Alabama	Tatum 1980	57.2	.362	0.616	19.8	.65	3.4	14.2	1.0
Apalachicola, Florida	Klima and Tabb 1959	78.4	.140	-0.456	20.3	.32	5.6	17.5	1.8
Cedar Key, Florida	Moffett 1961	114.4	.085	-0.814	22.0	.22	8.4	24.4	5.0
Fort Meyers, Florida	Moffett 1961	62.6	.214	-0.343	23.3	.49	3.6	14.1	0.9
Flamingo, Florida	Stewart 1961	85.2	.138	-0.579	25.0	.35	5.2	18.4	2.1
Combined	All of the above	65.5	.200	-0.411	22.0	.45	3.9	14.9	1.1

TABLE 2  
Current size and gill net restrictions on the harvest of spotted seatrout in the northern Gulf of Mexico.

	Florida	Alabama	Mississippi	Louisiana	Texas
Size limit					
Recreational	12 in. (but no size limit in Gulf and Franklin counties).	12 in.	None	None	14 in.
Commercial	12 in. (but no size limit in Gulf and Franklin counties).	Currently prohibited. Formerly 12 in.	12 in.	12 in.	Currently prohibited. Formerly 12 in.
Gill net mesh size (minimum)	Varies by local statutes or general statutes of local application or by rules of the Marine Fisheries Commission that are approved by the Governor and Cabinet.	Currently prohibited. Formerly 1.25 in. in Mobile County and 1.5 in. in Baldwin County.	1.5 in.	1.75 in.	Currently prohibited. Formerly 1.5 in.

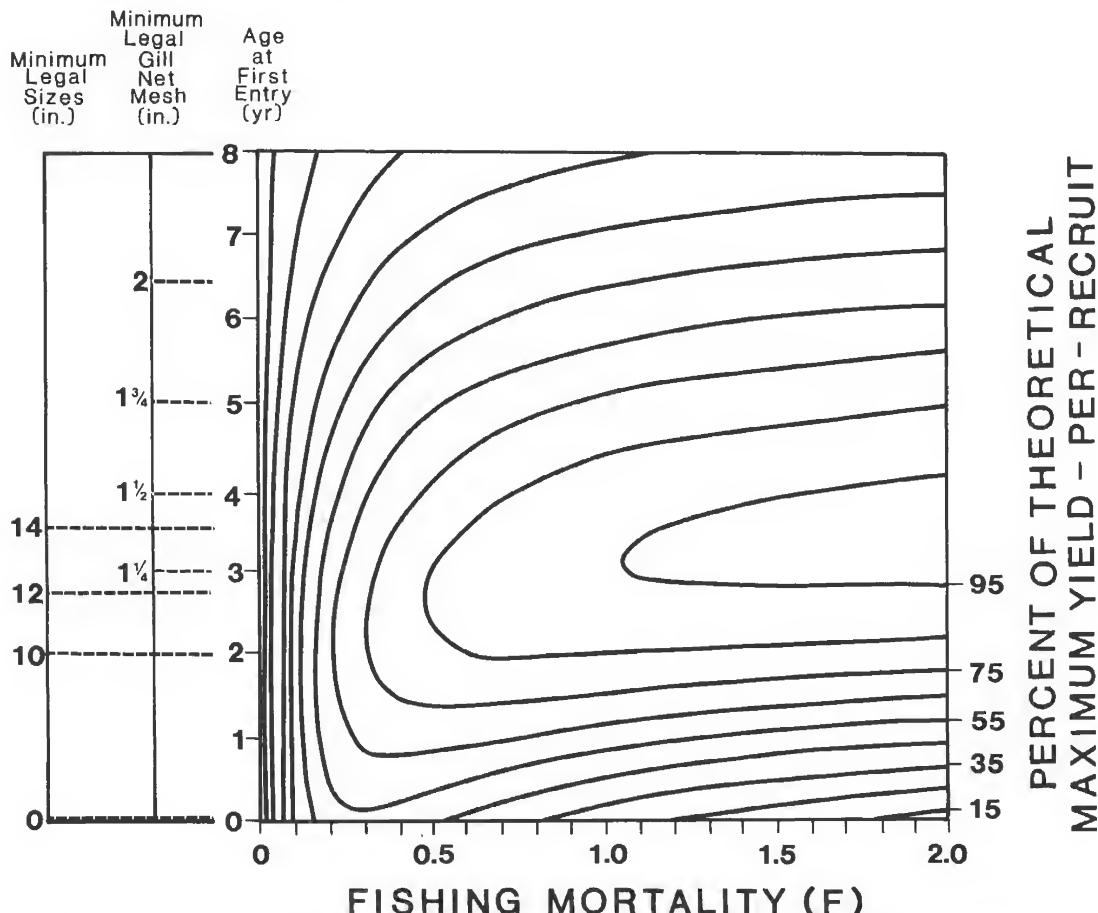


Figure 3. A yield-per-recruit contour for spotted seatrout in the northern Gulf of Mexico. Points indicate the entry levels associated with the current or recent Gulf state laws on minimum legal sizes of harvest and of gill net mesh (Table 2).

### *Effect on yield-per-recruit*

A yield-per-recruit contour was computed with Ricker's (1975) expanded form of Beverton's expression using these estimates, Harrington et al.'s (1979) length-weight relationship, and 12 years as an estimate of the maximum attainable age (Figure 3). Sizes of first entry as denoted by legal size limits (Table 2) and average size at entry predicted for gill net mesh limits are denoted for the respective states on the plot.

The fisheries of most concern are in Florida's Gulf and Franklin counties and in Louisiana and Mississippi's recreational fisheries since these fisheries have no legal minimum limits on the size of first harvest. As such any growth-overfishing concerns are superseded by the open nature of these fisheries since they are fully exposed to the potential for spawner-recruit overfishing.

The situation in Louisiana's commercial harvest has been greatly improved by two pieces of recent legislation (Ford 1984). The first reduced Louisiana's gill net mesh from 2.0 in. to 1.75 in., moving the gill net fishery from fish averaging 19.2 in. (6.4 yr, 2.4 lb) to those averaging 17.1 in. (5.0 yr, 1.7 lb). The second increased the minimum legal commercial harvest from 10 in. (2.0 yr, .33 lb) to 12 in. (2.7 yr, .57 lb).

On the other hand, Alabama and, perhaps, Texas have recently moved away from maximum yield per recruit. In both states commercial harvest has been recently prohibited. Before the prohibition the existing regulations targeted the

commercial harvest towards the size of fish which would maximize yield: 3–4 years old, 12–15 in., and 0.6–1.1 lb. Given our current estimate of fishing mortality for Alabama, this prohibition will reduce the overall yield for that state, unless it stimulates an increase in the recreational fishery. A similar pattern might be expected for Texas, although the situation is less clear as we have no direct estimate of fishing mortality for that state.

Since the spotted seatrout fishery has a large recreational component, management may be far more concerned with catch-per-angler-hour and spawner-recruit relationships than with yield-per-recruit. Our analysis suggests, however, that efforts to optimize catch-per-angler-hour and to maintain an adequate spawning biomass may be compatible with efforts to maximize yield-per-recruit. Yield appears to be maximized when spotted seatrout are harvested at 3.9 years. This age represents the second year of spawning activity. As such, management that provides for maximum yield-per-recruit, also reduces the danger of spawner-recruit overfishing (as compared to most current regulations), and enhances the recreational experience through the harvest of larger fish.

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#### ADDENDUM (in proof)

Since this paper was written, Mississippi and Florida have begun consideration of new regulations that would change the size restrictions in their states. In Mississippi it is probable that state regulations will be changed to make it illegal to sell, offer for sale, or transport for sale in or from the state of Mississippi, spotted seatrout under 14 in. In Florida it is possible that state regulations will be changed to make 14 in. the minimum size limit for spotted seatrout for both commercial and recreational fisheries. The Florida

regulation might or might not be applied statewide. If applied statewide in Florida's recreational and commercial fisheries and applied in Mississippi's commercial fisheries, the 14 in. minimum limit would target the harvest towards the size of fish that would maximize yield-per-recruit in these fisheries. On the other hand, if part of Florida remains exempt from this regulation that part, along with the recreational fisheries in Louisiana and Mississippi, will be fully exposed to the threat of spawner-recruit overfishing.

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Testis-Ova in Spawning Blue Tilapia, *Oreochromis aureus*

B. Clark

*University of South Florida*

H.J. Grier

*Florida Department of Natural Resources*

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## TESTIS-OVA IN SPAWNING BLUE TILAPIA, *OREOCHROMIS AUREUS*

B. CLARK AND H. J. GRIER

Department of Biology, University of South Florida, Tampa, Florida 33620  
and State of Florida Department of Natural Resources, St. Petersburg,  
Florida 33701-5095

**ABSTRACT** Hermaphroditism characterized by the presence of oocytes in the testes is described in the blue tilapia, *Oreochromis aureus*, for the first time. Testis-ova were observed in three of 24 spawning males exhibiting otherwise normal male morphology. The testis-ova appeared non-vitellogenic and lacked a follicle cell layer. It is speculated that the testis-ova did not become vitellogenic due to their association with Sertoli cells and the hormonal environment of the male.

### INTRODUCTION

Intersexuality characterized by oocytes in the testis has been well documented among teleost fishes (Atz 1964, Reinboth 1970, Borg and van der Hurk 1983, Grout 1983). Testis-ova are often found in individuals which exhibit marked intersexuality with gonads divided into distinct ovarian and testicular regions or possessing intermediate secondary sex characters. However, oocytes in otherwise normal males have been reported (Reinboth 1962, Lillelund

1965). In a study of hermaphroditism among "Mbuna" cichlids, Peters (1975) suggested that oocytes in a testis was not conclusive evidence for its being a secondary testis. Furthermore, several specimens examined in that study possessed testis-ova yet exhibited male behavior. During a chromosomal analysis of testicular preparations from the blue tilapia, *Oreochromis aureus*, we observed oocytes in testes of three spawning males. This report offers further evidence for the widespread occurrence of testis-ova among cichlids. To our knowledge, this is the first report of hermaphroditism in *O. aureus*.

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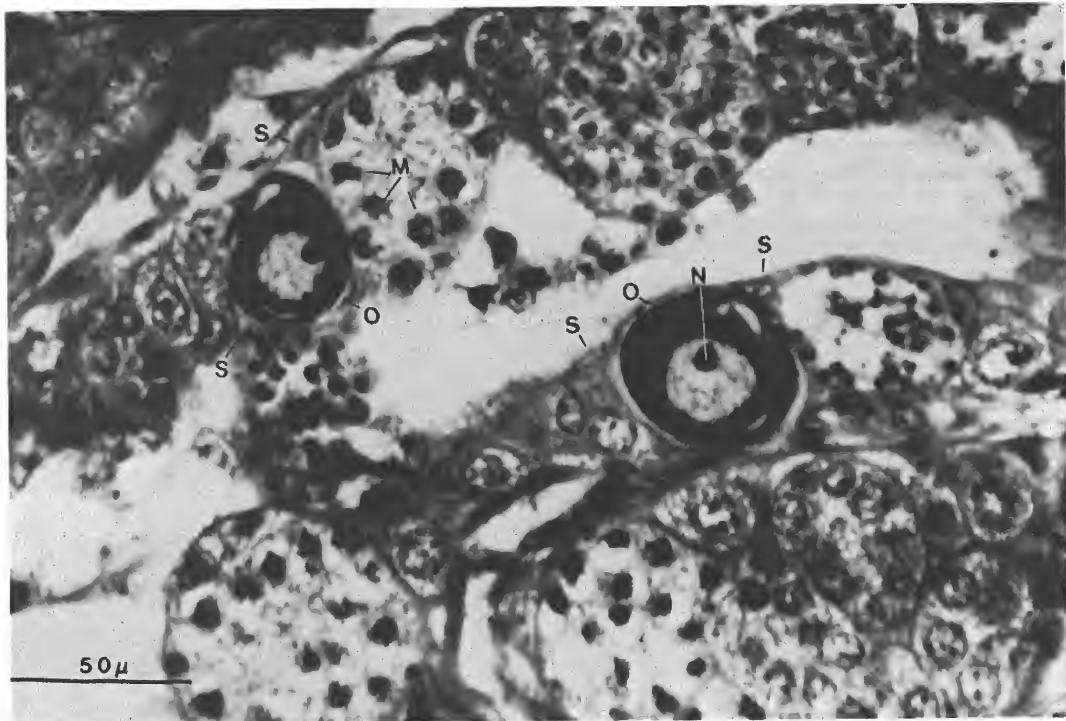


Figure 1. Testis-ova in a blue tilapia, *Oreochromis aureus*. Abbreviations: M = Mitotic spermatagonia, N = Nucleolus, O = Oocytes, S = Sertoli cells.

## MATERIALS AND METHODS

Twenty-four male blue tilapia were collected by cast netting in irrigation canals of the Hillsborough River (Hillsborough County, Florida) during March 1984. Each specimen received an intraperitoneal injection of 0.1 percent colchicine (Sigma) at a dose of 0.1 ml per 10 grams body weight 6 hours prior to death to accumulate mitotic cells for the chromosomal analysis. Dissected testes were fixed in Bouin's solution, dehydrated through absolute ethanol, and embedded in glycol methacrylate (Polysciences) (Cole and Sykes 1974). For light microscopy, transverse sections 4 microns thick were stained with toluidine blue.

## RESULTS AND DISCUSSION

All specimens examined were sexually mature and in breeding condition based on coloration and gonad size. Females possessed mature eggs within the ovary. Some were orally incubating eggs or fry.

Histologic examination of the testes revealed active spermatogenesis in all males with numerous meiotic and mitotic figures. In 3 of the 24 males, oocytes occurred among testicular tubules alongside normal spermatogenic

tissue (Figure 1). The oocytes (25 to 75 microns in diameter) were nonvitellogenic and often degenerate. In a few, small nucleoli were associated with the nuclear membrane, characteristic of oocytes in the first meiotic prophase (perinucleolar state). Most of the testis-oocytes, however, possessed a single large nucleolus. A distinct follicle cell layer encompassing the testis-oocytes was not present. Sertoli cell processes retained these oocytes within the spermatogenically active tissue of the testis and apparently prevented them from becoming free within the tubule lumen. We speculate that the oocytes did not become vitellogenic because Sertoli cells cannot function as follicle cells, particularly in the presence of male hormones. The Sertoli cells may also be phagocytosing follicular cells.

Differentiation of oocytes in testicular tissues remains enigmatic. This phenomenon, however, poses basic questions as to mechanisms of germ cell differentiation and illustrates the variable nature of the teleost gonad.

## ACKNOWLEDGMENT

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